CHAPTER 1: INTRODUCTION TO VOLUME TWO

INTRODUCTION

Coastal habitats provide ecological, cultural, and economic value. They act as critical habitat for thousands of species, including numerous threatened and endangered species, by providing shelter, spawning grounds, and food (Mitsch and Gosselink 2000). They often act as natural buffers, providing ecological, social, and economic benefits by filtering sediment and pollution from upland drainage thereby improving water quality, reducing the effects of floodwaters and storm surges, and preventing erosion. In addition to these ecosystem services, healthy coastal habitats provide many human values including opportunities for:

- Outdoor recreation and tourism
- Education
- Traditional use and subsistence lifestyles
- Healthy fishing communities, and
- Obtaining other marketable goods

Therefore, healthy functioning coastal habitats are not only important ecologically, they also support healthy coastal communities and, more generally, improve the quality of human lives. Despite these benefits, coastal habitats have been modified, degraded, and removed throughout the United States and its protectorates beginning with European colonization (Dahl 1990). Thus, many coastal habitats around the United States are in desperate need of restoration and subsequent monitoring of restoration projects.

WHAT IS RESTORATION MONITORING?

The science of restoration requires two basic tools: the ability to manipulate ecosystems to recreate a desired community and the ability to evaluate whether the manipulation has produced the desired change (Keddy 2000). The latter is often referred to as restoration monitoring.

For this manual, restoration monitoring is defined as follows:

> "*The systematic collection and analysis of data that provides information useful for measuring project performance at a variety of scales (locally, regionally, and nationally), determining when modification of efforts are necessary, and building long-term public support for habitat protection and restoration*."

Restoration monitoring contributes to the understanding of complex ecological systems (Meeker et al. 1996) and is essential in documenting restoration performance and adapting project and program approaches when needs arise. If results of monitoring restored coastal areas are disseminated, they can provide tools for planning management strategies and help improve future restoration practices and projects (Washington et al. 2000). Restoration monitoring can be used to determine whether project goals are being met and if mid-course corrections are necessary. It provides information on whether selected project goals are good measures for future projects and how to perform routine maintenance in restored areas (NOAA et al. 2002). Monitoring also provides the basis for a rigorous review of the pre-construction project planning and engineering.

Restoration monitoring is closely tied to and directly derived from restoration project goals. The monitoring plan (i.e., what is measured, how often, when, and where) should be developed with project goals in mind. If, for example, the goal of a restoration project is to increase the amount of fish utilizing a coastal marsh, then measurements should be selected that can quantify progress toward that goal. A variety of questions about sampling techniques and protocols need to be answered before monitoring can begin. For the fish utilization example, these may include:

- Will active or passive capture techniques be used (e.g., beach seines vs. fyke nets)?
- Where and when will samples be taken?
- Who will conduct the sampling?
- What level of identification will be required?
- What structural characteristics such as water level fluctuation or water chemistry will also be monitored and how?
- Who is responsible for housing and analyzing the data?
- How will results of the monitoring be disseminated?

Each of these questions, as well as many others, will be answered with the goals of the restoration project in mind. These questions need to be addressed before any measurements are taken in the field. In addition, although restoration monitoring is typically thought of as a 'post-restoration' activity, practitioners will find it beneficial to collect some data before and during project implementation. Pre-implementation monitoring provides baseline information to compare with post-implementation data to see if the restoration is having the desired effect. It also allows practitioners to refine sampling procedures if necessary. Monitoring during implementation helps insure that the project is being implemented as planned or if modifications need to be made.

Monitoring is an essential component of all restoration efforts. Without effective monitoring, restoration projects are exposed to several risks. For example, it may not be possible to obtain early warnings indicating that a restoration project is not on track. Without sound scientific monitoring, it is difficult to gauge how well a restoration site is functioning ecologically both before and after implementation. Monitoring is necessary to assess whether specific project goals and objectives (both ecological and human dimensions) are being met, and to determine what measures might need to be taken to better achieve those goals. In addition, the lack of monitoring may lead to poor project coordination and decreased efficiency.

Sharing of data and protocols with others working in the same area is also encouraged. If multiple projects in the same watershed or ecosystem are not designed and evaluated using a complementary set of protocols, a disjointed effort may produce a patchwork of restoration sites with varying degrees of success (Galatowitsch et al. 1998-1999) and no way to assess system-wide progress. This would result in a decreased ability to compare results or approaches among projects.

CONTEXT AND ORGANIZATION OF INFORMATION

In 2000, Congress passed the *Estuary Restoration Act (ERA), Title I of the Estuaries and Clean Waters Act of 2000*. The ERA establishes a goal of one million acres of coastal habitats (including those of the Great Lakes) to be restored by 2010. The ERA also declares that anyone seeking funds for a restoration project needs to have a monitoring plan to show how the progress of the restoration will be tracked over time. The National Oceanic and Atmospheric Administration (NOAA) was tasked with developing monitoring guidance for coastal restoration practitioners whether they be academics, private consultants, members of state, Tribal or local government, non-governmental organizations (NGOs), or private citizens, regardless of their level of expertise.

To accomplish this task, NOAA has provided guidance to the public in two volumes. The first, *Science-Based Restoration Monitoring of Coastal Habitats, Volume One: A Framework* *for Monitoring Plans Under the Estuaries and Clean Waters Act of 2000 (Public Law 160-457)* was released in 2003. It outlines the steps necessary to develop a monitoring plan for any coastal habitat restoration project. *Volume One* briefly describes each of the habitats covered and provides three matrices to help practitioners choose which habitat characteristics may be most appropriate to monitor for their project. Experienced restoration practitioners, biologists, and ecologists as well as those new to coastal habitat restoration and ecology can benefit from the step-by-step approach to designing a monitoring plan outlined in *Volume One*.

Volume Two, *Tools for Monitoring Coastal Habitats* expands upon the information in *Volume One* and is divided into two sections **Monitoring Progress Toward Goals** (Chapters 2-14) and **Context for Restoration** (Chapters 15-18). The first section, Monitoring Progress Toward Goals includes:

- Detailed information on the structural and functional characteristics of each habitat that may be of use in restoration monitoring
- Annotated bibliographies, by habitat, of restoration-related literature and technical methods manuals, and
- A chapter discussing many of the human dimensions aspects of restoration monitoring

The second section, Context for Restoration includes:

- A review of methods to select reference conditions
- A sample list of costs associated with restoration and restoration monitoring
- An overview of an online, searchable database of coastal monitoring projects from around the United States, and
- A review of federal legislation that supports restoration and restoration monitoring

The Audience

Volumes One and *Two* of *Science-Based Restoration Monitoring of Coastal Habitats* are written for those involved in developing and implementing restoration monitoring plans, both scientists and non-scientists alike. The intended audience includes restoration professionals in academia and private industry, as well as those in Federal, state, local, and Tribal governments. Volunteer groups, non-governmental organizations, environmental advocates, and individuals participating in restoration monitoring planning will also find this information valuable. Whereas *Volume One* is designed to be usable by any restoration practitioner, regardless of their level of expertise, *Volume Two* is designed more for practitioners who do not have extensive experience in coastal ecology. Seasoned veterans in coastal habitat ecology, however, may also benefit from the annotated bibliographies, literature review, and other tools provided.

The information presented in *Volume Two* is not intended as a 'how to' or methods manual: many of these are already available on a regional or habitat-specific basis. *Volume Two* does not provide detailed procedures that practitioners can directly use in the field to monitor habitat characteristics. The tremendous diversity of coastal habitats across the United States, the types and levels of impact to them, the differing scales of restoration activities, and variety of techniques used in restoration and restoration monitoring prevent the development of universal protocols. Thus, the authors have taken the approach of explaining *what one can measure during restoration monitoring, why it is important*, and *what information it provides* about the progress of the restoration effort. The authors of each chapter also believe that monitoring plans must be derived from the goals of the restoration project itself. Thus, each monitoring effort has the potential to be unique. The authors suggest, however, that restoration practitioners seek out the advice of regional experts, share data, and use similar data collection techniques with others in their area to increase the knowledge and understanding of their local and regional habitats. The online database of monitoring projects described in Chapter 17 is intended to facilitate this exchange of information.

The authors do not expect that every characteristic and parameter described herein will be measured, in fact, very few of them will be as part of any particular monitoring effort. A comprehensive discussion of all potential characteristics is, however, necessary so that practitioners may choose those that are most appropriate for their monitoring program. In addition, although the language used in *Volume Two* is geared toward restoration monitoring, the characteristics and parameters discussed could also be used in ecological monitoring and in the selection of reference conditions as well.

MONITORING PROGRESS TOWARDS GOALS

The progress of a restoration project can be monitored through the use of traditional ecological characteristics (Chapters 2 - 13) and/or emerging techniques that incorporate human dimensions (Chapter 14).

THE HABITAT CHAPTERS

Thirteen coastal habitats are discussed in twelve chapters. Each chapter follows a format that allows users to move directly to the information needed, rather than reading the whole text as one would a novel. There is, however, substantial variation in the level of detail among the chapters. The depth of information presented reflects the extent of restoration, monitoring, and general ecological literature associated with that habitat. That is, some habitats such as marshes, SAV, and oyster reefs have been the subject of extensive restoration efforts, while others such as rocky intertidal and rock bottom habitats have not. Even within habitats there can be considerable differences in the amount of information available on various structural and functional characteristics and guidance on selecting parameters to measure them. The information presented for each habitat has been derived from extensive literature reviews of restoration and ecological monitoring studies. Each habitat chapter was then reviewed by experts for content to ensure that the information provided represented the most current scientific understanding of the ecology of these systems as it relates to restoration monitoring.

Habitat characteristics are divided into two types: structural and functional. Structural habitat characteristics define the physical composition of a habitat. Examples of structural characteristics include:

- Sediment grain size
- Water source and velocity
- Depth and timing of flooding, and
- Topography and bathymetry

Structural characteristics such as these are often manipulated during restoration efforts to bring about changes in function. Functional characteristics are the ecological services a habitat provides. Examples include:

- Primary productivity
- Providing spawning, nursery, and feeding grounds
- Nutrient cycling, and
- Floodwater storage

Structural characteristics determine whether or not a particular habitat is able to exist in a given area. They will often be the first ones monitored during a restoration project. Once the proper set of structural characteristics is in place and the biological components of the habitat begin to become established, functional characteristics may be added to the monitoring program. Although structural characteristics have historically been more commonly monitored during restoration efforts, measurements of functional characteristics provide a better estimate of whether or not a restored area is truly performing the economic and ecological services desired. Therefore, incorporating measurements of functional characteristics in restoration monitoring plans is strongly encouraged.

When developing a restoration monitoring plan, practitioners should follow the twelve-step process presented in *Volume One* and refer to the appropriate chapters in *Volume Two* (habitat and human dimensions) to assist them in selecting characteristics to monitor. The information presented in the habitat chapters is derived from and expands upon the *Volume One* matrices (*Volume One* Appendix II).

Organization of Information

Each of the habitat chapters is structured as follows:

1. Introduction
   a. Habitat description and distribution
   b. General ecology
   c. Human impacts to the habitat
2. Structural and functional characteristics
   a. Each structural and functional characteristic identified for the habitat in the *Volume One* matrices is explained in detail. Structural and functional characteristics have generally been discussed in separate sections of each chapter. Occasionally, some functions are so intertwined with structural characteristics that the two are discussed together.
   b. Whenever possible, potential methods to measure, sample, and/or monitor each characteristic are introduced or readers are directed to more thorough sources of information. In some cases, not enough information was found while reviewing the literature to make specific recommendations. In these cases, readers are encouraged to use the primary literature cited within the text for methods and additional information.
3. Matrices of the structural and functional characteristics and parameters suggested for use in restoration monitoring
   a. These two matrices are habitat-specific distillations of the *Volume One* matrices
   b. Habitat characteristics are cross-walked with parameters appropriate for monitoring change in that characteristic. Parameters include both those that are direct measures of a particular characteristic as well as those that are indirectly related and may influence a particular characteristic or related parameter. Tables 1 and 2 can be used to illustrate an example. The parameter of salinity in submerged aquatic vegetation is a direct measure of a structural characteristic (salinity, Table 1). In addition, salinity is related to other structural characteristics such as tides and water source. Salinity is also related to functional characteristics such as biodiversity and nutrient cycling and may be appropriate to include in the monitoring of these functions as well (Table 2). Experienced practitioners will note that many characteristics and parameters may be related to one another but are not shown as such in a particular matrix. The matrices are not intended to be all inclusive of each and every possible interaction. The matrices provided and the linkages illustrated are only intended as starting points in the process of developing lists of parameters that may be useful in measuring particular characteristics and understanding some of their interrelationships.
   c. Some parameters and characteristics are noted as being highly recommended for any and all monitoring efforts as they represent critical components of the habitat while others may or may not be appropriate for use depending on the goals of the individual restoration project.
4. Acknowledgement of reviewers
5. Literature Cited

Three appendices are also provided for each habitat chapter. In the online form of *Volume Two,* these appendices download with the rest of the habitat chapter text. In the printed versions of *Volume Two*, each chapter's appendices are provided on a searchable CD-ROM located inside the back cover. Each appendix is organized as follows:

Appendix I - An Annotated Bibliography
a. Overview of case studies of restoration monitoring and general ecological studies pertinent to restoration monitoring
b. Entries are alphabetized by author

Parameters to Monitor the Structural Characteristics of SAV (excerpt)

Parameters to Monitor	**Biological**	Habitat created by plants	**Physical**	Sediment grain size[1]	Topography / Bathymetry	Turbidity	**Hydrological**	Tides / Hydroperiod	Water sources	Current velocity	Wave energy	**Chemical**	Nutrient concentration	pH, salinity, toxics, redox, DO[2]
Chemical														
Salinity (in tidal areas)								●	●					●

Table 1. Salinity is a parameter that can be used to directly measure a structural component of submerged aquatic vegetation habitats (Chemical/salinity). It is shown with a closed circle indicating that it highly recommended as part of any restoration monitoring program, regardless of project goals. A circle for salinity is also shown under the **Tides/Hydroperiod** and **Water source** columns as salinity levels are related to these structural characteristics as well. (Entire table can be found on page 9.39.)

Parameters to Monitor the Functional Characteristics of SAV (excerpt)

Parameters to Monitor	**Biological**	Contributes primary production	Supports biomass production	Provides breeding grounds	Provides nursery areas	Provides feeding grounds	Provides refuge from predation	Supports high biodiversity	Supports a complex trophic structure	Provides substrate for attachment	**Chemical**	Supports nutrient cycling	Modifies chemical water quality	Modifies dissolved oxygen
Chemical														
Salinity (in tidal areas)								❍				❍		

Table 2. Salinity is related to the functions of **Supporting high biodiversity** and **Supporting nutrient cycling**. It is shown here with an open circle, denoting that it may be useful to monitor if monitoring of these functions is important to the goals of the restoration project. (Entire table can be found on page 9.40.)

[1] Including organic matter content.
[2] Dissolved oxygen.

Appendix II - Review of Technical and Methods Manuals

These include reviews of:

a. Restoration manuals
b. Volunteer monitoring protocols
c. Lab methods
d. Identification keys, and
e. Sampling methods manuals

Whenever possible, web addresses where these resources can be found free of charge are provided.

Appendix III - Contact information for experts who have agreed to be contacted with questions from practitioners

As extensive as these resources are, it is inevitable that some examples, articles, reports, and methods manuals have been omitted. Therefore, these chapters should not be used in isolation. Instead, they should be used as a supplement to and extension of:

- The material presented in *Volume One*
- Resources provided in the appendices
- The advice of regional habitat experts, and
- Research on the local habitat to be restored

WHAT ARE THE HABITATS?

The number and type of habitats available in any given estuary is a product of a complex mixture of the local physical and hydrological characteristics of the water body and the organisms living there. The ERA Estuary Habitat Restoration Strategy (Federal Register 2002) dictates that the Cowardin et al. (1979) classification system should be followed in organizing this restoration monitoring information. The Cowardin system is a national standard for wetland mapping, monitoring, and data reporting, and contains 64 different categories of estuarine and tidally influenced habitats. Definitions, terminology, and the list of habitat types continue to increase in number as the system is modified. Discussion of such a large number of habitat types would be unwieldy. The habitat types presented in this document, therefore, needed to be smaller in number, broad in scope, and flexible in definition. The 13 habitats described in this document are, however, generally based on that of Cowardin et al. (1979).

Restoration practitioners should consider local conditions within their project area to select which general habitat types are present and which monitoring measures might apply. In many cases, a project area will contain more than one habitat type. To appropriately determine the habitats within a project area, the practitioner should gather surveys and aerial photographs of the project area. From this information, he or she will be able to break down the project area into a number of smaller areas that share basic structural characteristics. The practitioner should then determine the habitat type for each of these smaller areas. For example, a practitioner working in a riparian area may find a project area contains a *water column, riverine forest, rocky shoreline*, and *rock bottom*. Similarly, someone working to restore an area associated with a tidal creek or stream may find the project area contains *water column, marshes, soft shoreline, soft bottom*, and *oyster beds*. Virtually all estuary restoration projects will incorporate characteristics of the water column. Therefore, all practitioners should read *Chapter 2: Restoration Monitoring of the Water Column* in addition to any additional chapters necessary.

Habitat Decision Tree

A Habitat Decision Tree has been developed to assist in the easy differentiation among the habitats included in this manual. The decision tree allows readers to overcome the restraints of varying habitat related terminology in deciding which habitat definitions best describe those in their project area. Brief definitions of each habitat are provided at the end of the key.

1. a. Habitat consists of open water and does not include substrate (**Water Column**)
   b. Habitat includes substrate (go to 2)
2. a. Habitat is continually submerged under most conditions (go to 3)
   b. Habitat substrate is exposed to air as a regular part of its hydroperiod (go to 8)
3. a. Habitat is largely unvegetated (go to 4)
   b. Habitat is dominated by vegetation (go to 7)
4. a. Substrate is composed primarily of soft materials, such as mud, silt, sand, or clay (**Soft Bottom**)
   b. Substrate is composed primarily of hard materials, either of biological or geological origin (go to 5)
5. a. Substrate is composed of geologic material, such as boulders, bedrock outcrops, gravel, or cobble (**Rock Bottom**)
   b. Substrate is biological in origin (go to 6)
6. a. Substrate was built primarily by oysters, such as *Crassostrea virginica* (**Oyster Reefs**)
   b. Substrate was built primarily by corals (**Coral Reefs**)
7. a. Habitat is dominated by macroalgae (**Kelp and Other Macroalgae**)
   b. Habitat is dominated by rooted vascular plants (**Submerged Aquatic Vegetation - SAV**)
8. a. Habitat is not predominantly vegetated (go to 9)
   b. Habitat is dominated by vegetation (go to 10)
9. a. Substrate is hard, made up materials such as bedrock outcrops, boulders, and cobble (**Rocky Shoreline**)
   b. Substrate is soft, made up of materials such as sand or mud (**Soft Shoreline**)
10. a. Habitat is dominated by herbaceous, emergent, vascular plants. The water table is at or near the soil surface or the area is shallowly flooded (**Marshes**)
    b. Habitat is dominated by woody plants (go to 11)
11. a. The dominant woody plants present are mangroves, including the genera *Avicennia*, *Rhizophora*, and *Laguncularia* (**Mangrove Swamps**)
    b. The dominant woody plants are other than mangroves (go to 12)
12. a. Forested habitat experiencing prolonged flooding, such as in areas along lakes, rivers, and in large coastal wetland complexes. Typical dominant vegetation includes bald cypress (*Taxodium distichum*), black gum (*Nyssa sylvatica*), and water tupelo (*Nyssa aquatica*). (**Deepwater Swamps**)
    b. Forested habitat along streams and in floodplains that do not experience prolonged flooding (**Riverine Forests**)

Water column - A conceptual volume of water extending from the water surface down to, but not including the substrate. It is found in marine, estuarine, river, and lacustrine systems.

Rock bottom - Includes all wetlands and deepwater habitats with substrates having an aerial cover of stones, boulders, or bedrock 75% or greater and vegetative cover of less than 30% (Cowardin et al. 1979). Water regimes are restricted to subtidal, permanently flooded, intermittently exposed, and semi-permanently flooded. The rock bottom habitats addressed in *Volume Two* include bedrock and rubble.

Coral reefs - Highly diverse ecosystems, found in warm, clear, shallow waters of tropical oceans worldwide. They are composed of marine polyps that secrete a hard calcium carbonate skeleton, which serves as a base or substrate for the colony.

Oyster reefs - Dense, highly structured communities of individual oysters growing on the shells of dead oysters.

Soft bottom - Loose, unconsolidated substrate characterized by fine to coarse-grained sediment.

Kelp and other macroalgae - Relatively shallow (less than 50 m deep) subtidal and intertidal algal communities dominated by very large brown algae. Kelp and other macroalgae grow on hard or consolidated substrates forming extensive three-dimensional structures that support numerous plant and animal communities.

Rocky shoreline - Extensive littoral habitats on high-energy coasts (i.e., subject to erosion from waves) characterized by bedrock, stones, or boulders with a cover of 75% or more and less than 30% cover of vegetation. The substrate is, however, stable enough to permit the attachment and growth of sessile or sedentary invertebrates and attached algae or lichens.

Soft shoreline - Unconsolidated shore includes all habitats having three characteristics: (1) unconsolidated substrates with less than 75% aerial cover of stones, boulders, or bedrock; (2) less than 30% aerial cover of vegetation other than pioneering plants; and (3) any of the following water regimes: irregularly exposed, regularly flooded, irregularly flooded, seasonally flooded, temporarily flooded, intermittently flooded, saturated, or artificially flooded (Cowardin et al. 1979). This definition includes cobble-gravel, sand, and mud. However, for the purpose of this document, cobble-gravel is not addressed.

Submerged aquatic vegetation (SAV; includes marine, brackish, and freshwater) - Seagrasses and other rooted aquatic plants growing on soft sediments in sheltered shallow waters of estuaries, bays, lagoons, rivers, and lakes. Freshwater species are adapted to the short- and long-term water level fluctuations typical of freshwater ecosystems.

Marshes (marine, brackish, and freshwater) - Transitional habitats between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water tidally or seasonally. Freshwater species are adapted to the short- and long-term water level fluctuations typical of freshwater ecosystems.

Mangrove swamps - Swamps dominated by shrubs (*Avicenna, Rhizophora*, and *Laguncularia*) that live between the sea and the land in areas that are inundated by tides. Mangroves thrive along protected shores with fine-grained sediments where the mean temperature during the coldest month is greater than 20º C; this limits their northern distribution.

Deepwater swamps - Forested wetlands that develop along edges of lakes, alluvial river swamps, in slow-flowing strands, and in large coastal-wetland complexes. They can be found along the Atlantic and Gulf Coasts and throughout the Mississippi River valley.

They are distinguished from other forested habitats by the tolerance of the dominant vegetation to prolonged flooding.

Riverine forests - Forests found along sluggish streams, drainage depressions, and in large alluvial floodplains. Although associated with deepwater swamps in the southeastern United States, riverine forests are found throughout the United States in areas that do not have prolonged flooding.

THE HUMAN DIMENSIONS CHAPTER

The discussion of human dimensions helps restoration practitioners better understand how to select measurable objectives that allow for the appropriate assessment of the benefits of coastal restoration projects to human communities and economies. Traditionally, consideration of human dimensions issues has not been included as a standard component of most coastal restoration projects. Most restoration programs do not currently integrate social or economic factors into restoration monitoring, and few restoration projects have implemented full-scale human dimensions monitoring. Although some restoration plans are developed in an institutional setting that require more deliberate consideration of human dimensions impacts and goals, this does not generally extend to the monitoring stage. It is becoming increasingly evident, however, that decisions regarding restoration cannot be made solely by using ecological parameters alone but should also involve considerations of impacts on and benefits to human populations, as well. Local communities have a vested interest in coastal restoration and are directly impacted by the outcome of restoration projects in terms of aesthetics, economics, or culture. Human dimensions goals and objectives whether currently available or yet to be developed should reflect societal uses and values of the resource to be restored. Establishing these types of parameters will increase the public's understanding of the potential benefits of a restoration project and will increase public support for restoration activities.

While ecologists work to monitor the restoration of biological, physical, and chemical functional characteristics of coastal ecosystems, human dimensions professionals identify and describe how people value, utilize, and benefit from the restoration of coastal habitats. The monitoring and observation of coastal resource stakeholders allows us to determine who cares about coastal restoration, why coastal restoration is important to them, and how coastal restoration changes people's lives. The human dimensions chapter will help restoration practitioners identify:

1) Human dimensions goals and objectives of a project
2) Measurable parameters that can be monitored to determine if those goals are being met, and
3) Social science research methods, techniques, and data sources available for monitoring these parameters

This chapter includes a discussion of the diverse and dynamic social values that people place on natural resources, and the role these values play in natural resource policy and management. Additionally, some of the general factors to consider in the selection and monitoring of human dimensions goals/objectives of coastal restoration are presented, followed by a discussion of some specific human dimensions goals, objectives, and measurable parameters that may be included in a coastal restoration project. An annotated bibliography of key references and a matrix of human dimensions goals and measurable parameters are provided as appendices at the end of this chapter. Also included, as an appendix, is a list of human dimensions research experts (and their areas of expertise) that you may contact for additional information or advice.

The final four chapters of this manual are designed to provide readers with additional information that should enhance their ability to develop and carry out strong restoration monitoring plans. Chapter 15 reviews methods available for choosing areas or conditions to which a restoration site may be compared both for the purpose of setting goals during project planning and for monitoring the development of the restored site over time. Chapter 16 is a listing of generalized costs of personnel, labor, and equipment to assist in the development of planning preliminary cost estimates of restoration monitoring activities. Some of this information will also be pertinent to estimating costs of implementing a restoration project as well. Chapter 17 provides a brief description of the online review of monitoring programs in the United States. The database can be accessed though the NOAA Restoration Portal (http://restoration.noaa.gov/). This database will allow interested parties to search by parameters and methodologies used in monitoring, find and contact responsible persons, and provide examples that could serve as models for establishment or improvement of their own monitoring efforts. Chapter 18 is a summary of the major United States Acts that support restoration monitoring. This information will provide material important in the development of a monitoring plan. A Glossary of many scientific terms is also provided at the end of the document.

References

Cowardin, L. M., V. Carter, F. C. Golet and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States, 104 pp. FWS/OBS-79/31, U.S. Fish and Wildlife Service, Washington, D.C.

Dahl, T. E. 1990. Wetland loss in the United States 1780's to 1980's, United States Department of Interior, Fish and Wildlife Service, Washington, D.C.

ERA. 2000. Estuary Restoration Act of 2000: Report (to accompany H.R. 1775) (including cost estimate of the Congressional Budget Office). Corp Author(s): United States. Congress. House. Committee on Transportation and Infrastructure. U.S. G.P.O., Washington, D.C.

Federal Register. 2002. Final estuary habitat restoration strategy prepared by the estuary habitat restoration council. December 3. 71942-71949.

Galatowitsch, S. M., D. C. Whited and J. R. Tester. 1998-1999. Development of community metrics to evaluate recovery of Minnesota wetlands. *Journal of Aquatic Ecosystem Stress and Recovery* 6:217-234.

Keddy, P. A. 2000. Wetland Ecology: Principles and Conservation. Cambridge University Press, Cambridge, United Kingdom.

Meeker, S., A. Reid, J. Schloss and A. Hayden. 1996. Great Bay Watch: A Citizen Water Monitoring Programpp. UNMP-AR-SG96-7, University of New Hampshire/University of Maine Sea Grant College Program.

Mitsch, W. J. and J. G. Gosselink. 2000. Wetlands. Third ed. Van Nostrand Reinhold, New York, NY.

NOAA, Environmental Protection Agency, Army Corps of Engineers, United States Fish and Wildlife Service and Natural Resources Conservation Service. 2002. An Introduction and User's Guide to Wetland Restoration, Creation, and Enhancement (pre-print copy), Silver Spring, MD.

Washington, H., J. Malloy, R. Lonie, D. Love, J. Dumbrell, P. Bennett and S. Baldwin. 2000. Aspects of Catchment Health: A Community Environmental Assessment and Monitoring Manual. Hawkesbury-Nepean Catchment Management Trust, Windsor, Australia.

CHAPTER 7: RESTORATION MONITORING OF SOFT BOTTOM HABITATS

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INTRODUCTION

Soft bottom habitats within coastal environments are characterized by loose, unconsolidated sediment types (Cowardin et al. 1979). The sediments are fine to coarse-grained with at least 25% of the particles smaller than 2 cm and have a vegetative cover less than 30%. Soft bottom habitats are restricted to subtidal, permanently flooded water regimes, characterized by the general lack of areas for plant and animal attachment and by lower energy levels than rocky substrate habitats. The composition of plants and animals present is determined by temperature, salinity, light penetration, and the substrate type that is, in turn, structured by the exposure to wave and current action. Managing the ecological health of soft bottom habitats is integral to managing the health of aquatic systems as a whole. Many organisms live in and on sediments and use sedimentary particles as food. Crustaceans, polychaetes, and gastropods dominate these habitats and are the primary sources of food for many of the larger estuarine organisms such as fish (Boesch et al. 1994).

Soft bottom habitats are often classified into four subclasses:

- Cobble-gravel, composed of unconsolidated particles smaller than stones, predominantly cobble and gravel, although finer sediments may be intermixed
- Sand-type, composed of unconsolidated particles smaller than gravel, predominantly sand, although finer or coarser sediments may be intermixed
- Mud, consisting of unconsolidated particles smaller than gravel, predominantly silt and clay, although coarser sediments or organic material may be intermixed
- Organic, composed of unconsolidated material smaller than gravel and is predominantly organic (Miner 1950; Smith 1964; Abbott 1968; and Ricketts and Calvin 1968)

The composition of the sea bottom (i.e., fine mud, sand, gravel, cobble, boulders, and rock) determines which plants and animals live in particular areas.

In freshwater areas, substrate type is largely determined by current velocity. Within the Great Lakes, soft bottom habitats tend to develop in low energy zones such as harbors, embayments, or drowned river mouths. The plants and animals present in and on the sediment surface also exhibit a high degree of morphological and behavioral adaptation to flowing water. Usually there is a high correlation between the nature of the substrate and the number and abundance of species. For example, when light is present and oxygen is high, sediments tend to be lower in ooze-like organic material and higher in species diversity.

In marine waters, soft bottom habitats are generally found in relatively shallow water (< 30 m) and adjacent to beaches (or other sediment sources). Marine soft bottom habitats include worm mounds and sand dollar beds and are not vegetated.

Soft bottom habitats perform a variety of functions beneficial to humans and wildlife. They act as filters for runoff from upland development and help moderate nutrient flow to downstream waters. Soft bottom communities recycle nutrients from the water column and

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other habitats. Organic detritus from kelp and other macroalgae, dead animals, zooplankton, phytoplankton, and other sources of nutrients and carbon rain down on the substrate where they can be eaten by benthic animals. This dead and/or decomposed material along with the associated nutrients are then buried and stored in the sediment. Occasionally, if sediments are disturbed, buried nutrients can make their way back into the water column where plants can once again use them. Research into the nutrient cycling dynamics of soft sediment communities has provided helpful management information for flatfish and other commercial species (Kaiser et al. 2000). Benthic communities can also be used to assess the presence of pollution in the water column as contaminants in the water column settle and accumulate in soft sediments.

HUMAN IMPACTS

Sediment contamination is an environmental problem that poses a threat to a variety of aquatic ecosystems. Sediments act as a reservoir for common chemicals such as pesticides, herbicides, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons, and metals. Contaminated sediments are directly toxic to aquatic life and can be a source of contaminants to humans through bioaccumulation in the food chain. Studies conducted by the United States Environmental Protection Agency (EPA) suggest that contaminated sediments are among the most significant sources of non-point source pollution in the United States and pose one of the largest risks to the aquatic environment. Many of the organic contaminants listed above bond well to the smaller grain sizes found in soft bottom sediments (Kukkonen et al. 2003).

The impact of fishing gear on marine benthic habitats is dependent upon the benthic species and fishing effort (Kaiser et al. 2000). The size of benthic species populations are positively associated with the availability of high quality nursery habitats (Turner 1977; Cibb et al. 1999). Unfortunately, relatively few studies of habitat disturbance have included a temporal component (study over time) of sufficient duration to address longer-term changes that occur as a result of bottom fishing disturbance. Collie et al. (2000) found the vulnerability of animals was based on morphology and behavior. Lugworms (*Arenicola* spp.), for example, have a large initial response to disturbance, which is not surprising given that these animals are the target of a commercial fishery. When fishing effort data is collected at a small spatial (~10 km^2) resolution (Rijnsdorp et al. 1998), fish effort is patchily distributed, and some relatively small areas of the seabed are scoured frequently (200-400 times a year) while others go unfished. This suggests that re-colonization of disturbed, heavily fished areas is more likely to come from active immigration into disturbed patches rather than reproduction within patches. When sampling soft bottom habitats, practitioners need to know the intensity of fishing in the restoration area as well as adjacent habitats that may contribute individuals during restoration of the habitat.

STRUCTURAL CHARACTERISTICS OF SOFT BOTTOM HABITATS

Estuarine/wetland sediments are affected by physical, hydrological, and chemical forces. Soft bottom habitats are characterized by variable physical and chemical conditions that influence the organisms living in these habitats. There are often large changes in physical-chemical parameters with increasing depth. Concentration of dissolved components such as oxygen, for example, can fluctuate considerably. Tides and tidal currents can also move large amounts of water and suspended material around within the habitat and between soft bottoms and adjacent areas. The structural characteristics of soft bottom habitats that influence these biological, physical, and chemical functions include:

Physical
- Sediment grain size
- Topography/Bathymetry

Hydrological
- Current velocity

Chemical
- Nutrient concentration
- DO
- Sediment Contaminants

PHYSICAL

Understanding the many physical forces acting on soft bottoms is essential to understanding the ecology of this habitat type. Major sediment inputs to soft bottom habitats are deposited by the annual flow of rivers into estuaries. During fall and winter there are numerous resuspension events that move particles at different rates. Physical factors such as temperature, light, turbidity, currents, and wave action interact to form soft bottom habitats that are characterized by zones of low energy, little plant life, and high deposition of sediments.

Sediment Grain Size

Grain size is the most fundamental physical property of sediment. Geologists and sedimentologists use information on sediment grain size to study:

- Trends in surface processes related to the dynamic conditions of transportation and deposition
- The permeability and stability under different sediment loads, and
- The movement of subsurface fluids (McCave and Syvitski 1991)

With these reasons in mind, the objectives of a grain-size analysis are to accurately measure individual particle sizes, to determine their frequency distribution, and to calculate a statistical description that characterizes the sample.

Classification schemes for benthic invertebrate communities have been developed based on sediment texture: i.e., the proportion of silt, clay, sand, and water. (Boswell 1961; Jones 1956). Biomass is greater in muddy sand compared to other textures. Sanders (1956) identified a soft-bottom polychaete-mollusc community in Long Island Sound on the basis of sediment texture. Hughes et al. (1972) observed that 46% of the polychaetes and echinoderms in a coastal bay were associated with an area of soft sediments.

The sediment type and grain size is important in determining the benthic community composition because behavioral and morphological adaptations evolve to suit a specific substrate. For example, flatfish body shapes can dig into the sediment and their coloration and markings mimic their surroundings. Clams and worms also prefer a certain grain size and depth. Because sediment grain size controls how easily fish bury and the type of prey dwelling within, each species and life stage prefers a specific size. Sediments that differ in grain size also differ in other properties that are important to organisms. Algae and bacteria, for example, are found in greater abundance in softer sediments. The distribution and abundance patterns of amphipods such as *Diporeia* spp. reveal a positive relationship with sediment-associated bacteria (Sly and Christie 1992).

Sampling and Monitoring Methods

The characteristics of coastal sediment particles are shaped by variations in the hydrological conditions affecting the littoral area of soft sediment habitats. The source of sediments from the surrounding source area also will determine the hardness, shape, and ultimately the size of sediment particles. Important physical conditions in the littoral zone include the oscillating nature of seasonal wave patterns and the seasonal deposition of sediments during river floods. There can be considerable variability in sediment grain size over short periods of time (hours to weeks), therefore these changes are usually considered as "noise" compared to the spatial distribution of sediment types. Thus, repeated measurements over the short-term are less important than the sampling over a larger area to determine source and connection to open waters (Guillén and Hoekstra 1996).

Sediment grain size can be measured directly by drying and sifting samples through a series of different sized sieves (Poppe et al. 2003). It can also be measured indirectly through measuring bulk density. Bulk density is the dry weight of the sediment per unit of volume (Steyer et al. 1995). It is generally low (e.g., 0.2 to 0.3 g/cm^3) for sediments with high organic matter content and high (e.g., 1.0 to 2.0 g/cm^3) for sediments with high mineral content (Mitsch and Gosselink 2000). Detailed methods for sampling sediment characteristics such as grain size, nutrient concentration, and organic content can be found in Folk (1974), Gosselink and Hatton (1984), Poppe et al. (1986; 2000), Liu and Evett (1990), and Steyer et al. (1995), as well as other resources listed in the second appendix of this chapter.

Topography/Bathymetry

As mentioned earlier, soft bottom habitats are found in a variety of settings, usually associated with reduced water flow and high deposition rates. The sediments in these habitats consist of three primary components: particulate mineral matter, organic matter in various stages of decomposition, and an inorganic component of biogenic origin such as diatom shells. Particle size and organic matter of sediments is important to the distribution and growth of benthic invertebrates. Sediments with large amounts of organic matter are found in areas associated by high rates of littoral production (Wetzel 1983).

Sampling and Monitoring Methods

Sedimentation rate, nutrient cycling, and other important physical processes are defined by the topography of the soft bottom habitat. The bathymetric features of soft bottoms can be sampled using a boat and a method to measure depth such as a weighted rope, pole, or radar. Methods will vary depending on the amount of detail desired and the size of the habitat being mapped. For larger areas or where more detail is desired, remote sensing techniques can be used. High-resolution aerial imagery can be used to create detailed maps of bathymetry over large areas that would be hard to sample with traditional methods. These technologies (LIDAR, multi-beam sonar, and side-scan sonar) have been successfully demonstrated in mapping estuary and marsh topography (Blomgren 1999; Barnes et al. 2002; Clayton et al. 2002; Gardner and Mayer 2002; Pickrill and Todd 2002). Imagery can also be analyzed to determine different sediment types (Lee et al. 2001; Dierssen et al. 2003; Louchard et al. 2003).

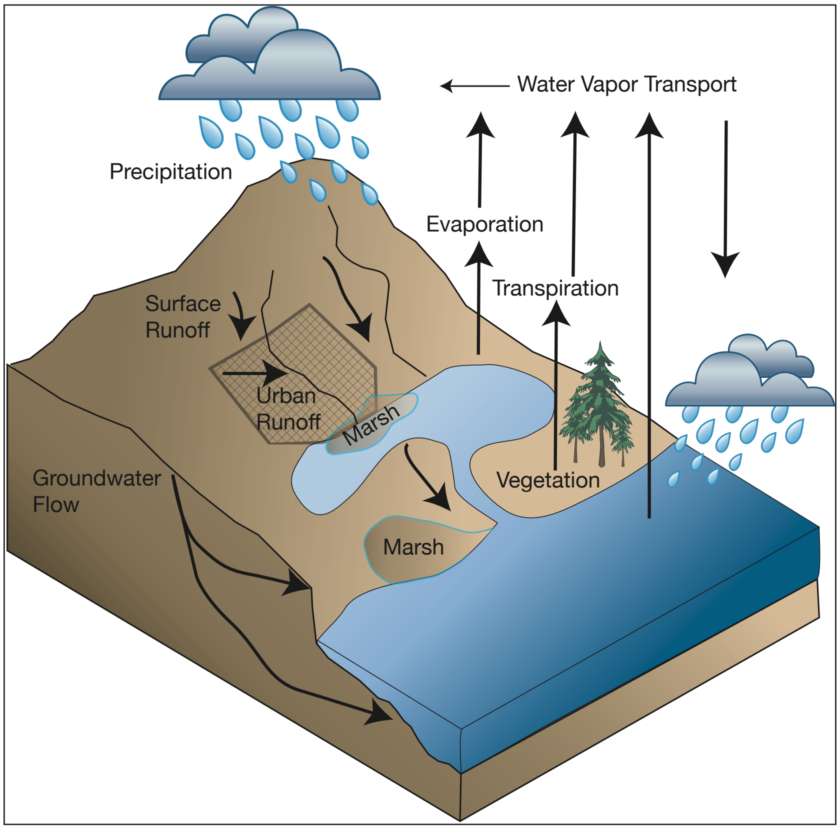

Figure 1. The hydrologic cycle. As water returns to earth as rain, it carries with it a variety of suspended and dissolved material on its return to open bodies of water. The characteristics of the land over and through which water flows determines the characteristics of the water once it reaches its destination. Graphic by Stephen Lozano, NOAA Great Lakes Environmental Research Laboratory.

HYDROLOGICAL

Hydrologic processes play an important role in the transportation of sediments to soft bottom habitats. Nutrients, sediments, toxic compounds, and metals are delivered to soft bottom habitats through groundwater flow, surface runoff, and precipitation (Figure 1). Land use also impacts the quality of water reaching soft sediments by affecting evaporation rates, the amount of water infiltrating to ground water, and the rate of run-off and erosion.

Current Velocity

Geological character and history shape the distribution of sediment and substrate, but the speed and direction of currents help determine the grain size of soft bottom materials such as silt and sand. In general, faster current areas contain more coarse-grained sediments. Ripple marks and sand waves are also indicative of very strong currents (Driskell 1979). Movement of bottom sediments by waves and currents is a dominant physical process influencing the structure of benthic communities in soft bottom areas (Oliver 1980; Simenstad et al. 1991).

Sediments enter and settle in the estuary from both terrestrial and open-water resources. As rivers and creeks flow seaward, they carry with them sediments from the land, while flood tides bring in sands from the sea (de Johge and van Beusekom 1995). The runoff from rains and snowmelt also carries sediments into nearby streams. Removal of vegetation from agricultural, logging, and construction operations promotes erosion and increases the sediment loads of rivers and creeks.

The size of sediments in soft bottom habitats ranges from small rocks and coarse gravel to silt and clay particles. The faster the current, the greater the size of sediment particles a stream can move. In the slower currents of a river's lower reaches, only the finest sediments will remain suspended in the water. In the tidewater portion of the river, fine sediments begin settling out and are deposited in several ways. In large flood tides, the river currents stop or even reverse course, allowing even finer particles to rain out. In a process called flocculation, tiny particles clump together, become heavier, and settle to the bottom. This occurs in estuaries where freshwater meets and mingles with salt water, particles collide and stick together forming larger aggregates or clumps of sediments called flocs which then settle out of suspension. Consequently, deposition can change along the course of the estuary. Sediments are also deposited wherever currents are slowed, such as the bend of a stream where sediments will settle and create shallows.

CHEMICAL

Nutrient Concentration

Large areas of sediments in soft bottom habitats are able to exchange nutrients with overlying regions of the estuary or wetland where plants can grow. Most of the nutrients are nitrogen and phosphorous from agricultural sources but also from human waste and industrial discharge. Microbial activity, burrowing animals, and resuspension of sediments increase the release of nutrients into the water. High concentrations of nutrients in the water column stimulate algal growth, eutrophication, oxygen depletion, and ultimately, fish kills due to lack of oxygen. It has been shown that bottom sediments directly influence water quality by releasing nitrogen to overlying waters and by consuming dissolved oxygen from the water column in the process. High primary productivity may, in turn, alter the entire benthic community composition and possibly the species composition of higher levels in the food chain (Burkholder 1998).

Animals also affect the physical, chemical, and biological aspects of their environment. Feeding by freshwater deposit feeders such as oligochaetes and the burrowing amphipod *Diporeia* spp. can mix sediments by highly ordered or random movement of sediment particles (McCall and Tevesz 1982). The mixing of sediments is not a feeding strategy but is created by suspension feeders, deposit feeders, and omnivores as they move, burrow, and feed in the sediments. The mixing of sediments by *Diporeia* is important in the Great Lakes. Robbins et al. (1979) found that ^{137}C labeled clay was uniformly distributed in the top 1.5 cm of a sediment column. The net effect of amphipod feeding and burrowing activity is to mix sediments randomly. Similar to polychaetes in marine waters, oligochaetes are among the most potent movers of sediments in fresh water. In Lake George, 85% of the worm population was found below 12 cm (Brinkhurst and Kennedy 1965).

Another important component of soft bottom sediments is the organic carbon content. Sediment organic matter is derived from plant and animal detritus, bacteria, plankton, or derived from natural and anthropogenic sources in catchments. Organic matter in sediment consists of carbon and nutrients in the form of carbohydrates, proteins, fats, and nucleic acids. Bacteria quickly eat nucleic acids and many of the proteins. Sediment organic matter can be a source of recycled nutrients for water column productivity when it degrades. Dissolved oxygen (DO) concentrations are usually lowered when organic aerobic bacteria degrade matter, and anoxic and hypoxic conditions may develop under stratified conditions.

Sampling and Monitoring Methods

Sampling, handling, and processing nutrient samples requires special instrumentation and reagents. Methods for measuring nutrients in bottom sediments are summarized in *Standard Methods for the Examination of Water and Wastewater* (1998). More information on monitoring nutrient concentrations in estuarine habitats is available at: http://www.epa.gov/owow/estuaries/monitor.

Dissolved Oxygen (DO)

The level of oxygen in fine sediments can become limiting for all aquatic life. In addition to its use in respiration in plants and larger animals such as fish, DO is used by bacteria in the process of breaking down organic matter. A characteristic feature of all sediments is a vertical zonation into a surface layer with oxygen and a subsurface layer where dissolved oxygen is depleted. Vertical distribution of sediment plants and animals is restricted by these vertical gradients. Bacteria are important in creating this zonation. Bacteria use oxygen as a hydrogen acceptor and are found to a depth that oxygen can penetrate the surface sediments. Below this depth are bacteria capable of anaerobic respiration and chemosynthesis. Under conditions of very low or no oxygen, many benthic taxa are eliminated (Boesch et al. 1976).

Sampling and Monitoring Methods

Measurements of DO should be taken at least weekly. Measurements should be year round but are particularly important during the growing season. Methods for measuring DO in bottom sediments are summarized in *Standard Methods for the Examination of Water and Wastewater* (1998). A variety of electronic oxygen sensors are commercially available.

Sediment Contaminants

Contaminated sediments are directly toxic to aquatic life or can be a source of contaminants for bioaccumulation in the food chain. Contaminated sediments are among the most significant sources of non-point source pollution in the United States and pose one of the largest risks to the aquatic environment. The U.S. Environmental Protection Agency has published a manual on new methods for testing freshwater organisms in the laboratory to evaluate the potential toxicity or bioaccumulation of chemicals in whole sediments (USEPA 1994). The *Standard Methods for the Examination of Water and Waste Water* (1998) also provides extensive methods for measuring a variety of chemical contaminants.

FUNCTIONAL CHARACTERISTICS OF SOFT BOTTOM HABITATS

Many of the physical and chemical functions performed by soft bottom habitats were covered with the associated structural characteristics above. The following section focuses on the biological functions. A list of common functional characteristics of soft bottom habitats includes:

Biological
- Provides habitat for the benthic community

Physical
- Alters turbidity

Chemical
- Modifies chemical water quality
- Modifies dissolved oxygen
- Supports nutrient cycling

BIOLOGICAL

Provides Habitat for the Benthic Community

The benthic community of soft bottom habitats is composed of a wide range of bacteria, plants, and animals. The most important function of benthic organisms is to link primary producers, such as phytoplankton, with the higher trophic levels, such as finfish, by consuming phytoplankton and then being consumed by larger organisms. They also play a major role in breaking down organic material. Another important functional characteristic of soft bottom habitats is the transformation of chemicals by bacteria and other microorganisms (Figure 2). Transformation

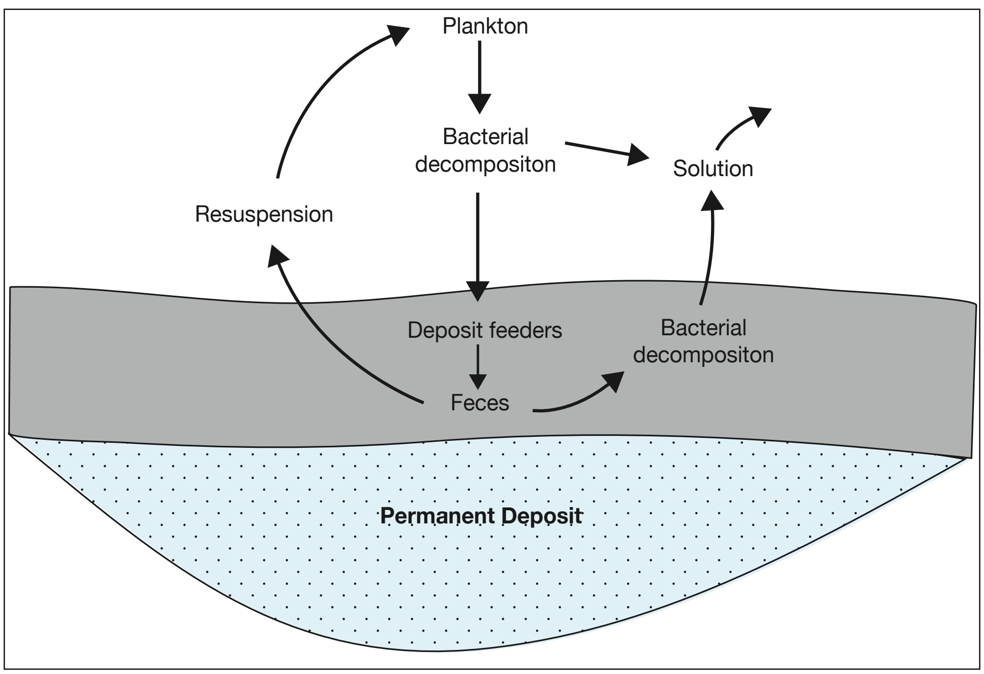

Figure 2. Bacterial recycling of organic matter. As phytoplankton and zooplankton die, the decomposition by bacteria begins in the water column. Deposit feeders (e.g. oligochaetes, amphipods) also break down pelagic material. Organic matter is re-suspended from feces or bacterial decomposition of fecal material. Graphic by Stephen Lozano, NOAA Great Lakes Environmental Research Laboratory.

reactions are intimately tied to the deposition of organic matter. Some of the most important transformation reactions resulting from bacteria decomposition of organic matter are the removal of dissolved oxygen, the production of carbon dioxide, the reduction of nitrate, the reduction of sulfate, and the production of ammonia, phosphate, hydrogen sulfide, and methane (Berner 1974; Alongi 1997).

The use of benthos in aquatic ecological research, and particularly in evaluating marine pollution, is effective in assessing long-term changes and detecting input from diffuse sources (Boesch et al. 1976; Simboura et al. 1995; Hyland et al. 1996). The benthos reflects the effects of pollutants or organic enrichment by responding through measurable changes in population size on a time scale of weeks to years. Benthic assemblages are used because they consist of largely sessile organisms that must tolerate the pollution or die. Benthic organisms are resident year round, naturally abundant and diverse, and most are not harvested or intentionally managed by humans. Benthic monitoring is a relatively sensitive, effective, and reliable technique that can detect subtle changes that serve as an early indicator before more drastic environmental changes occur. Some benthic taxa are able to tolerate high levels of organic enrichment and low dissolved oxygen, while others are quickly eliminated under low DO conditions (Boesch et al. 1976). Benthic indices have been developed based on the ability of benthic taxa to tolerate different levels of DO, organic enrichment, pesticides, and metal contaminants (USEPA 1994).

Macroinvertebrates

The restoration and monitoring of fresh and salt-water soft bottom habitats begins with the benthic community, usually the benthic macroinvertebrates associated with specific sediment types. Benthic animals are divided into three distinct groups: infauna (animals that live in the sediment), epifauna (animals living on the surface of the sediment or other substrate such as debris), and demersal (bottom-feeding or bottom-dwelling fish and other free moving organisms). This division also reflects differences in sampling techniques for the three groups.

In estuarine soft bottom systems, the benthic community is dominated primarily by species that burrow into the sediments (infauna), either living within tubes or burrow systems. Dominant types of infauna in most estuaries are segregated by salinity and include:

- Small worms (polychaetes and oligochaetes)
- Amphipod crustaceans
- Clams, and
- Insect larvae

In temperate regions, the diversity, or species richness, of the benthic communities in soft substrates on the continental shelf and slope may rival that in shallow tropical seas (Brusca and Brusca 1990). Benthic animals generally consume detrital or planktonic food sources with some predatory species present, and are in turn prey for finfish, shrimp, and crabs.

The diversity of benthic invertebrates is large. In marine soft bottom habitat, the dominant benthic organisms include:

- Worms (polychaetes)
- Amphipods
- Clams
- Crabs, and
- Sea urchins (Simenstad et al. 1991; Ward 1975)

In habitats with gravel substrates, dominant animals are the mussels *Modiolus* and *Mytilus*, the brittle star *Amphipholis*, the soft-shell clam *Mya*, and the Venus clam *Saxidomus*. In sandy areas (Figure 3) dominant animals include:

- Wedge shells (*Donax* spp.)
- Scallops (*Pecten* spp.)
- Tellin shells (*Tellina* spp.)

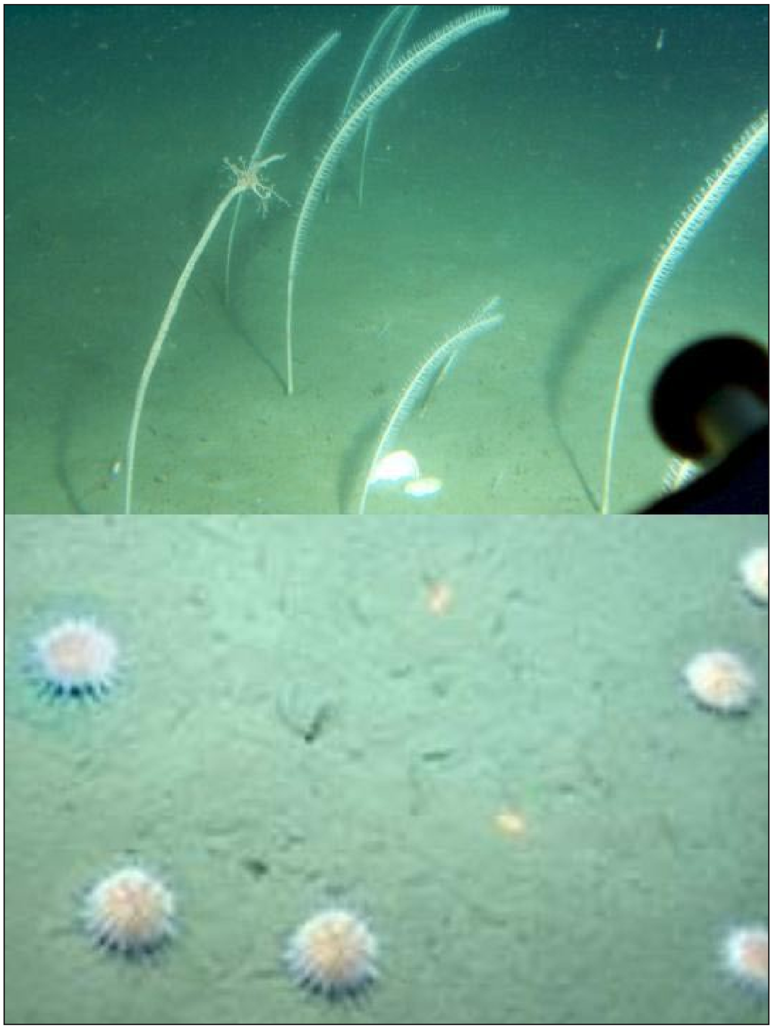

Figure 3. Sea urchins and fans on soft sediments, examples of animals that live on soft bottoms in marine estuaries. Photos from NOAA National Ocean Service.

Heart urchins (*Echinocardium* spp.)
Lugworms
Sand dollars (*Dendraster* spp.), and
Sea pansies (*Renilla* spp.)

In mud, dominant types include:

Terebellid worms (*Amphitrite* spp.)
Boring clams (*Platyodon* spp.)
Deep-sea scallops (*Placopecten* spp.)
Quahogs (*Mercenaria* spp)
Macomas (*Macoma* spp.)
Echiurid worms (*Urechis* spp.)
Mud snails (*Nassarius* spp.), and
Sea cucumbers (*Thyone* spp.) (Miner 1950; Smith 1964; Abbott 1968; Ricketts and Calvin 1968; Hodgson and Nybakken 1973).

Within the Great Lakes, much of the fauna of soft bottom habitats in wetlands are characterized by low abundance, high diversity, and great variability in both time and space. This variability is due to the physical instability of this habitat. Downwelling and oscillating thermoclines cause wide fluctuations in bottom temperatures, and waves and bottom currents cause resuspension of bottom substrates (Cook and Johnson 1974). Dominant freshwater benthic organisms include:

Oligochaetes (*Stylodrilus heringianus*, *Tubifex* spp., *Limnodrilus* spp.)
Amphipods (*Diporeia*, *Gammarus* spp.)
Mayflies (*Hexagenia* spp.)
Pea mussels (*Pisidium* spp), and
Chironomid larvae (Chironomidae) (Pennak 1978; Barton and Hynes 1978)

Sampling

The soft-bottom, infaunal benthos can be sampled relatively well by retrieving quantitative samples of the sediment and sieving them to extract the fauna. Grabs and corers are the devices generally used for sampling benthic invertebrates. Holme (1964), Holme and McIntyre (1971), and McInyre et al. (1984) have reviewed a large variety of grab and corer devices generally used for sampling benthic invertebrates. A review of methods for collecting and processing benthic samples can also be found in EVS Environment Consultants (1993), USEPA (1987), and USEPA (2001).

PHYSICAL

The main physical function performed by soft bottom habitats (alteration of turbidity) was described with the associated structural characteristics.

CHEMICAL

The main chemical functions performed by soft bottom habitats (modification of chemical water quality, modification of dissolved oxygen, and support of nutrient cycling) were described with their associated structural characteristics.

PARAMETERS FOR MONITORING STRUCTURAL/FUNCTIONAL CHARACTERISTICS

The matrices of structural and functional parameters for restoration monitoring provided below was developed through extensive review of the restoration and ecological monitoring literature. Additional input was received from recognized experts in the field of soft bottom ecology. This listing of parameters is not exhaustive, it is merely intended as a starting point to help restoration practitioners develop monitoring plans for this habitat type. Additional parameters not in this list, such as human dimensions parameters, may also be appropriate for restoration monitoring efforts. Parameters with a closed circle (●) are those that, at the minimum, should be considered in monitoring restoration progress. Parameters with an open circle (❍) may also be monitored depending on specific restoration goals. Information on why these parameters are important for monitoring and how they relate to structural and functional characteristics as well as to one another is found throughout the text. Literature directing readers toward additional information on the ecology of soft bottom habitats and restoration case studies can be found in Appendix I, an annotated bibliography of soft bottoms. Information on sampling strategies and techniques can be found in Appendix II, a review of technical methods manuals.

Parameters to Monitor the Structural Characteristics of Soft Bottom Habitats

Parameters to Monitor	**Physical**	Sediment grain size	Topography / Bathymetry	**Hydrological**	Current velocity	**Chemical**	pH, salinity, toxics, redox, DO
Hydrological							
Physical							
Shear force at sediment surface					❍		
Water column current velocity					●		
Chemical							
Dissolved oxygen							❍
Nitrogen and phosphorus							
Salinity (in tidal areas)							●
Toxics							❍
Soil/Sediment							
Physical							
Basin elevations			❍				
Geomorphology (slope, basin cross section)			●				
Organic content		●					
Percent sand, silt, and clay		●					
Sedimentation rate and quality		●	●		●		
Chemical							
Dissolved oxygen							❍
Salinity (in tidal areas)							❍
Toxics							❍

Parameters to Monitor the Functional Characteristics of Soft Bottom Habitats

Parameters to Monitor	Biological	Physical	Chemical		
	Provides habitat for benthic community	Alters turbidity	Modifies chemical water quality	Modifies dissolved oxygen	Supports nutrient cycling
Geographical					
Acreage of habitat types	●	●	●	●	●
Biological					
Animals					
Species, composition, and abundance of:					
Fish	❍				
Invasives	❍				
Invertebrates	●				
Hydrological					
Physical					
Current velocity		❍			
Trash		❍			
Chemical					
Chlorophyll concentration		❍	❍	❍	❍
Dissolved oxygen	❍		❍	❍	❍
Nitrogen and phosphorus		❍	❍		❍
PH			❍		
Toxics	❍		❍		
Soil/Sediment					
Physical					
Basin elevations	❍				
Sediment grain size (OM[3]/sand/silt/clay/gravel/cobble)		●	●	●	●
Sedimentation rate and quality		●			
Trash	❍				
Chemical					
Organic content in sediment		❍	❍	❍	❍

[3] Organic matter

Acknowledgments

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References

Abbott, R. T. 1968. Seashells of North America. Golden Press, New York, NY.

Alongi, D. M. 1997. Coastal Ecosystem Processes. CRC Press, New York, NY.

Barnes, P. W., G. W. Fleischer, J. V. Gardner and K. M. Lee. 2002. Using laser technology to characterize substrate morphology of lake trout spawning habitat in Northern Lake Michigan. Symposium on the Effects of Fishing Activities on Benthic Habitats: Linking Geology, Biology, Socioeconomics, and Management. Tampa, FL. November 12-14, 2002.

Barton, D. R. and H. B. N. Hynes. 1978. Wave-zone macrobenthos of the exposed Canadian shores of the St. Lawrence Great Lakes. *Journal of Great Lakes Research* 4:27-45.

Berner, R. A. 1974. Kinetic models for the early diagenesis of nitrogen, sulfur, phosphorus, and silicon in anoxic marine sediments, In The Sea, E.D. Goldberg, ed. Volume 54, pp. 427-450, John Wiley and Sons, NY.

Blomgren, S. 1999. A digital elevation model for estimating flooding scenarios at the Falsterbo Peninsula. *Environmental Modelling & Software with Environment Data News* 14:579-587

Blomgren, S. 1999. A digital elevation model for estimating flooding scenarios at the Falsterbo Peninsula. *Environmental Modelling & Software with Environment Data News* 14:579-587

Boesch, D. F., R. J. Diaz and R. W. Virnstein. 1976. Effects of tropical storm Agnes on soft-bottom macrobenthic communities of the James and York River estuaries and the lower Chesapeake Bay. *Chesapeake Science* 17:246-259.

Boesch, D. F., M. N. Josselyn, A. J. Mehta, J. T. Morris, W. K. Nuttle, C. A. Simenstad and D. J. P. Swift. 1994. Scientific assessment of coastal wetland loss, restoration and management in Louisiana. *Journal of Coastal Research* Special Issue 20:103

Boswell, P. G. H. 1961. Muddy Sediments. Heffer Co., Cambridge, MA

Brinkhurst, R. O. and C. R. Kennedy. 1965. Studies on the biology of the Tubificidae (Annelida, Oligochaeta) in a polluted stream. *Journal of Animal Ecology* 34:429-443.

Brusca, R. C. and G. J. Brusca. 1990. *Invertebrates*, Sinauer Associates, Sunderland.

Clayton, T. D., J. C. Brock and C. W. Wright. 2002. Mapping seagrass boundaries with waveform-resolving lidar: a preliminary assessment. Symposium on the Effects of Fishing Activities on Benthic Habitats: Linking Geology, Biology, Socioeconomics, and Management. Tampa, FL. November 12-14, 2002.

Cook, D. G. and M. G. Johnson. 1974. Benthic invertebrates of St. Lawrence Great Lakes. *Journal of the Fisheries Research Board of Canada* 31:763-782.

Collie, J. S., S. J. Hall, M. J. Kaiser and I. R. Poiner. 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. *Journal of Animal Ecology*, 69:785-799.

Cowardin, L. M., V. Carter, F. C. Golet and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. 131 pp.U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C.

de Johge, V. N. and J. E. E. van Beusekom. 1995. Wind- and tide-induced resuspension of sediment and macrobenthos from tidal flats in the Ems estuary. *Limnology and Oceanography* 40:766-771.

EVS Environment Consultants. 1993. Guidelines for Monitoring Benthos in Freshwater Environments. Prepared for: Environment Canada, 224 West Esplanade, North Vancouver, B.C. http://www.rem.sfu.ca/FRAP/gmbf.pdf

Gardner, J. V. and L. A. Mayer. 2002. Benthic habitat mapping with advanced technologies and their application. Symposium on the Effects of Fishing Activities on Benthic Habitats: Linking Geology, Biology, Socioeconomics, and Management. Tampa, FL. November 12-14, 2002.

Guillen, J., and P. Hoekstra, 1997, Sediment distribution in the nearshore zone: grain size evolution in response to shoreface nourishment (island of Terschelling). *Estuarine, Coastal and Shelf Science* 45:639-652

Hodgson, A. T. and J. Nybakken. 1973. A quantitative survey of the benthic infauna of northern Monterey Bay, California; final summary data report for August 1971 through February 1973. Technical Publication 73-8. Moss Landing Marine Laboratories.

Holme, N. A.1964. Methods of sampling the benthos. *Advances in Marine Biology* 2:171-260.

Holme, N. A. and A. D. McIntyre 1971.Methods for the study of marine benthos. 334 pp. IBP Handbook # 16 Blackwell, Oxford, U.K.

Hughes, R. N., D. L. Peer and K. H. Mann, 1972. Use of multivariate analysis to identify functional components of the benthos in St. Margaret's Bay. *Limnology and Oceanography* 17:111-121.

Hyland, J. L., T. J. Herlinger, T. R. Snouts, A. H. Ringwood, R. F. Van Dolah, C. T. Hackney, G. A. Nelson, J. S. Rosen and S. A. Kokkinakis. 1996. Environmental quality of estuaries of the Carolinian Province: 1994. Annual statistical summary for the 1994 EMAP – Estuaries Demonstration Project in the Carolinian Province. NOAA Technical Memorandum NOSORCA 97. 102 pp. NOAA/NOS, Office of Ocean Resources Conservation and Assessment, Silver Spring, MD.

Jones, N. S. 1956. The fauna and biomass of a muddy sand deposit off Port Erin, I.O.M. *Journal of Animal Ecology* 25:217-252.

Kaiser, M. J., K. Ramsay, C. A. Richardson, E. F. Spence, and A. R. Brand. 2000. Chronic fishing disturbance has changed shelf sea benthic community structure. *Journal of Animal Ecology* 69:494-503.

Kukkonen, J. V. K., P. F. Landrum, S. Mitra, D. C. Gossiaux, J. Gunnarson and D. Weston. 2003. Sediment characteristics affecting the desorption kinetics of select PAH and PCB congeners for seven laboratory-spiked sediments. *Environmental Science and Technology* 37:4656-4663.

McCall, P. L. and M. J. S. Tevesz. 1982. Animal-Sediment Relations: The Biogenic Alteration of Sediments. Plenum Press, New York, NY.

McCave, I. N. and J. P. M. Syvitski. 1991. Principles and methods of geological particle size analysis. In Syvitski, J.P.M. (ed.) Principles, Methods and Application of Particle Size Analysis. Cambridge University Press, New York, NY.

McIntyre, A. D., J. M. Elliot and D. V. Ellis. 1984. Introduction: Design of sampling programmes. pp. 1-26. In Methods for the study of marine benthos. N.A. Holme and A.D. McIntyre (eds.), Blackwell Scientific, Oxford.

Miner, R. W. 1950. Field book of seashore life. G. P Putnam's Sons, New York, NY.

Oliver, J. S. 1980. Processes affecting the organization of marine soft-bottom communities in Monterey Bay, California and McMurdo Sound, Antarctica. Ph.D. Thesis, University of California, San Diego, CA

Pennak, R. W. 1978. Fresh-water invertebrates of the United States. 2nd Edition. John Wiley & Sons, New York, NY.

Pickrill, R. A. and B. J. Todd. 2002. Sea floor mapping on the Scotian Shelf and the Gulf of Maine: implications for the management of ocean resources. Symposium on the Effects of Fishing Activities on Benthic Habitats: Linking Geology, Biology, Socioeconomics, and Management. Tampa, FL. November 12-14, 2002.

Poppe, L. J., A. H. Eliason and J. J. Fredericks. 1986, APSAS: An automated particle-size analysis system. *Computers & Geosciences* 12:93-96.

Poppe, L. J., A. H. Eliason, J. J. Fredericks, R. R. Rendigs, D. Blackwood and C. F. Polloni. 2000, Grain-size analysis of marine sediments: methodology and data processing: U.S. Geological survey open-file report 00-358. http://pubs.usgs.gov/of/of00-358/text/contents.htm

Oliver, J. S. 1980. Processes affecting the organization of marine soft-bottom communities in Monterey Bay, California and McMurdo Sound, Antarctica. Ph.D. Thesis, University of California, San Diego, CA.

Ricketts, E. F. and J. Calvin. 1968. Between Pacific tides, 4th ed. Revised by J. W. Hedgpeth. Stanford University Press, Stanford, CA.

Rijnsdorp, A. D, A. M. Buys, F. Storbeck and E. G. Visser. 1998. Micro-scale distribution of beam trawl effort in the southern North Sea between 1993 and 1996 in relation to the trawling frequency of the sea bed and the impact on benthic organisms. *ICES Journal of Marine Science* 55:403-419.

Robbins, J. A., P. L. McCall, J. B. Fisher and J. R. Krezoski. 1979. Effect of deposit feeders on migration of ^{137}Cs in lake sediments. *Earth Planet. Sci. Lett*. 42:277-287.

Sanders, H. L. 1956. Oceanography of long Island Sound. The biology of Marine bottom communities. *Bull. Bingham Oceanogr. Coll*. 15:245-258.

Simboura, N., A. Nicolaidou and M. Thessalou-Legaki. 2000. Polychaete communities of Greece: An ecological overview. *Marine Ecology-Pubblicazioni Della Stazione Zoologica Di Napoli I* 21: 129-144.

Simenstad, C. A., C. D. Tanner, R. M. Thom and L. L. Conquest. 1991. Estuarine Habitat Assessment Protocol. EPA 910/9-91-037. United States Environmental Protection Agency, Region 10, Office of Puget Sound, Seattle, WA.

Sly, P. G. and W. J. Christie. 1992. Factors influencing densities and distribution of *Pontoporeia hoyi* in Lake Ontario. *Hydrobiologia* 235/236:321-352.

Smith, R. I. 1964. Keys to Marine Invertebrates of the Woods Hole Region. Contribution No. 11. 208 pp. Systematics-Ecology Program Marine Biology Lab., Woods Hole, MA.

Standard Methods for Examination of Water and Wastewater, 20th ed., 1998. Available from the American Public Health Association, 1015 18th Street, N.W., Washington, D.C.

USEPA. 1987. *Recommended Guidelines for Sampling Marine Sediment, Water Column, and Tissue in Puget Sound.* USEPA Region 10 Office of Puget Sound and Puget Sound Water Quality Authority.

USEPA. 1994. Methods for Measuring the Toxicity and Bioaccumulation of Sediment-associated Contaminants with Freshwater Invertebrates - Second Edition, EPA/600/R-94/024. National Service Center for Environmental Publications, Cincinnati, OH.

USEPA. 2001. Methods for Collection, Storage, and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual, EPA/823/B-01/002. Office of Water. http://www.epa.gov/waterscience/cs/collection.html

Ward, J. V. 1975. Bottom fauna-substrate relationships in a northern Colorado trout stream: 1945 and 1974. *Ecology* 56:1429-1434.

Wetzel, R. G. 1983. Limnology (2nd ed.). Saunders Publishing, Forth Worth, TX.

APPENDIX I: SOFT BOTTOM HABITATS ANNOTATED BIBLIOGRAPHY

This annotated bibliography contains summaries of restoration case studies and basic ecological literature. It is designed to provide restoration practitioners with examples of previous restoration projects as well as overviews of papers from the ecological literature that offer more detail than that covered in the associated chapter. Entries are presented from both peer reviewed and grey literature. They were selected through extensive literature and Internet searches as well as input from reviewers. They are not, however, a complete listing of all of the available literature. Entries are arranged alphabetically. Wherever possible, web addresses or other contact information has been included in the reference to assist readers in easily obtaining the original resource. Summaries preceded by the terms '*Author Abstract'* or *'Publisher Introduction*' or similar descriptors were taken directly from their original source. Summaries without such descriptors were written by the authors of the associated chapter.

Alongi, D.M. 1998. Coastal Ecosystem Processes. CRC Press, Boca Raton, LA.

Editors Comments. This book is about how food webs process energy and nutrients in the coastal ocean. I have taken a process-functional approach to show not only how coastal ecosystems reply on exchanges among biota, but also how they are influenced by physical, chemical, and geological forces.

Barnes, P.W., G.W. Fleischer, J.V. Gardner and K.M. Lee. 2002. Using laser technology to characterize substrate morphology of lake trout spawning habitat in Northern Lake Michigan. Symposium on the Effects of Fishing Activities on Benthic Habitats: Linking Geology, Biology, Socioeconomics, and Management. Tampa, FL. November 12-14, 2002.

Author Abstract. As part of a strategy to re-establish devastated native lake trout stocks, six areas of offshore and coastal Lake Michigan habitat were mapped with SHOALS bathymetric lidar in late summer 2001 in cooperation with the U.S. Army Corps of Engineers. Decimeter elevation/bathymetric data referenced to IGLD85 datum were obtained on a 4 m grid over a total area of about 200 km^2 in water depths from 0 to 30 m. Shaded relief and color-coded depth images were developed within coarser regional gridded bathymetry and subaerial DEM as a basis for maps and initial interpretation. Sparse substrate samples, underwater diver and useful but local video observations supplement the morphologic information. Three geologic regimes are present in the area and form the basis for substrate, habitat and morphologic classification. Devonian and Silurian carbonates underlie the region. Morphologic scarps and bedding lineations suggest bedrock at or near the surface at all of the mapped areas, but confirmation is lacking. Overlying bedrock are glacial deposits including compacted clay tills and outwash gravel and sand. The orphology and video observations suggest NW-SE basal till lineations and small (1-3 km) cobble and boulder moraines with outwash deposits. Post-glacial reworking appears minimal in depths greater than 10m. Modern sand deposits appear as thin down-drift (to the east) bedforms, sand sheets and depositional lobes, except along the coast of Little Traverse Bay where well developed, en-echelon nearshore bars are present at the head of the bay. Laser waveform data is being analyzed for benthic albedo information and biologic data is being incorporated with the morphologic and geologic observations toward classifying and mapping preferred lake trout spawning habitat.

Bedford, K. W. 1992. The physical effects of the Great Lakes on tributaries and wetlands. *Journal of Great Lakes Research* 18:571-589.

Author Abstract. Wetlands and tributary confluences are susceptible to physical influences imposed by the Great Lakes, particularly through the effects of short and long-term water level fluctuations and accompanying transport disruptions including flow and transport reversals. With there being few, if any, direct observations of these disruptions based upon velocity measurements, the objective of this paper is to review the possible physical effects on these regions by first, reviewing the relevant contributing physics known about the Great Lakes; second, contrasting possible marine estuary transport mechanisms with what little is published about the Great Lakes circumstances; and third, summarizing modeled results exemplifying these behaviors from a study of Sandusky Bay, Lake Erie. Because it exhibits the strongest response to storms and the clearest measurable signals resulting from them, attention is centered on Lake Erie. In contrast to a typical research paper, the objective herein is to provide a summary of what is known and commonly accepted about these physics which can serve as a backdrop for the other papers in this special issue.

Clayton, T.D., J.C. Brock and C.W. Wright. 2002. Mapping seagrass boundaries with waveform-resolving lidar: A preliminary assessment. Symposium on the Effects of Fishing Activities on Benthic Habitats: Linking Geology, Biology, Socioeconomics, and Management. Tampa, FL. November 12-14, 2002.

Author Abstract. For ecologists and managers of seagrass systems, the spatial context provided by remote sensing has proven to be an important complement to *in situ* assessments and measurements. The spatial extent of seagrass beds has been mapped most commonly with conventional aerial photography. Additional remote mapping and monitoring tools applied to seagrass studies include optical satellite sensors, airborne multispectral scanners, underwater video cameras, and towed sonar systems. An additional tool that shows much promise is airborne, waveform-resolving lidar (light detection and ranging). Now used routinely for high-resolution bathymetric and topographic surveys, lidar systems operate by emitting a laser pulse, then measuring its two-way travel time from the plane to reflecting surface(s) below, then back to the detector co-located with the laser transmitter. Using a novel, waveform-resolving lidar system developed at NASA -- the Experimental Advanced Airborne Research Lidar (EAARL) -- we are investigating the possibility of using the additional information contained in the returned laser pulse (waveform) for the purposes of benthic habitat mapping. Preliminary analyses indicate that seagrass beds can potentially be delineated on the basis of apparent bathymetry, returned waveform shape and amplitude, and (horizontal) spatial texture. A complete set of georectified digital camera imagery is also collected during each EAARL overflight and can aid in mapping efforts. Illustrative examples are shown from seagrass beds in the turbid waters of Tampa Bay and the relatively clear

Day, J. W., Jr., C. A. S. Hall, W. M. Kemp and A. Y.-A. (eds.). 1989. Estuarine Ecology. John Wiley and Sons, NewYork.

Editor's Comments. Estuaries are critical to the life cycles of fish and other aquatic animals. This book is a comprehensive synthesis of the field of estuarine ecology, incorporating much new research not covered by other books. The authors provide up-to-date information on the structure and function of estuaries, integrating the various components and processes of these key ecosystems. They also present a classification of estuaries bases on ecological principles. *Estuarine Ecology* is suitable as a text, for it presents all relevant background material – and it is complete and well-referenced enough to serve as a standard reference. Specific environmental impacts are addressed and classified.

Initial chapters describe the physical and chemical aspects of estuaries, with emphasis on nutrient cycling, and show how these fundamental factors provide a setting for the study of estuarine ecology. Middle chapters address estuarine plants, microbial ecology, estuarine consumers, and fish life-history patterns. Considerable information is provided on rates, patterns, and factors controlling primary production; the role of detritus in coastal systems (a topic that has been important in estuarine ecology for thirty years); and estuarine consumers (zooplankton, benthos, nekton, and wildlife). Of special note is the importance of estuaries in supporting fisheries.

Estuarine Ecology also deals with the effects of civilization on estuaries, including commercial fishing, and the side effects of industry and development. The authors examine traditional approaches to fisheries management, then present a modern ecological viewpoint. In the final chapter they present a general classification of the effects of human activities on estuarine ecology and give examples of each.

Estuarine Ecology is a thorough introduction to the subject – it presents an acceptable synthesis of modern estuarine science for those new to the field and develops sophisticated analysis for the professional.

Gardner, J. V. and L. A. Mayer. 2002. Benthic habitat mapping with advanced technologies and their application. Symposium on the Effects of Fishing Activities on Benthic Habitats: Linking Geology, Biology, Socioeconomics, and Management. Tampa, FL. November 12-14, 2002.

Author Abstract. Today's ability to map the seafloor was unheard of two decades ago. Navigational accuracies, as well as spatial and elevation resolutions have now reached the decimeter scale. But are today's resolutions fine enough for biologists trying to characterize specific benthic habitats? Do biologists know what resolutions are necessary to define their benthic habitat of interest? Once biologists have high-resolution data, do they have the technologies to visualize and analyze their newly acquired data? Do Agencies have the budgets required to use 21st century technology? High-resolution seafloor mapping technologies come in a variety of flavors with a variety of resolutions, from airborne lidar to underwater photography. Each system has it's own pros and cons relative to the particular goal of the seafloor mapper. For instance, a living platform coral reef can be efficiently mapped with an airborne lidar but the spatial resolution is 2 m x 2 m, at best, with a depth resolution of a few centimeters. The data are spectacular, albeit costly. But are these resolutions good enough to characterize the platform coral reef habitat for biological or management purposes? If not, then maybe underwater video/still photography is required. Underwater video/still photography is very labor intensive to acquire and process into useful imagery. Although the spatial resolution can be millimeter-scale, there is poor vertical resolution unless stereo photography is collected. And, to map an entire platform coral reef with underwater video or still photography would be an enormous undertaking and expensive. Examples of several seafloor-mapping techniques will be shown and their pros and cons will be discussed.

Guerra-Garcia, J.M. and J.C. Garcia-Gomez. 2004. Soft bottom mollusc assemblages and pollution in a harbour with two opposing

entrances. *Estuarine Coastal and Shelf Science* 60: 273-283.

Author Abstract. Conventional harbours, provided with only one entrance and devoid of channels, are enclosed areas with low water renewal, high sedimentation rate and high concentrations of pollutants in sediments; the soft bottom communities are characterised by low species richness and low values of the diversity and evenness indexes. The harbour of Ceuta, North Africa, presents an unusual structure since it is provided with two opposing entrances and a channel, which increase the water renewal across the middle of the harbour. These unusual characteristics turn the harbour of Ceuta into an adequate locality to test its environmental implications on macrofaunal assemblages. In the present study, the spatial distribution of mollusc community associated with soft bottoms was studied in relation to the influence of environmental factors on the harbour of Ceuta and nearby areas, North Africa. Twenty-one stations (15 inside and six outside the harbour) were sampled and 26 variables were measured in the sediment of each station: depth, % sand, organic matter, lipids, P, N, Al, As, B, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Na, Ni, Pb, S, Sr, Zn. The special configuration of Ceuta Harbour created a great variability in sediment characteristics and environmental measures depending on the stations and, due to this heterogeneity, the mollusc species richness in the sediments inside the harbour (45 species) was higher than in conventional harbours. The multivariate approach based on MDS analysis was much more sensitive than univariate techniques to detect differences between internal and external stations of the harbour of Ceuta. The percentage of sand was the main factor to affect the distribution of the mollusc assemblages according to the BIO-ENV procedure and the CCA. SIMPER showed that the bivalves *Parvicardium exiguum, Ervilia castanea, Spisula subtruncata* and *Digitaria digitata* were the species that most contributed to the dissimilarity between internal and external stations; *P. exiguum, S. subtruncata* and *D. digitata* were more abundant in the internal stations whereas *E. castanea* was more abundant in the external stations. The bivalves *P. exiguum, Abra alba* and *Corbula gibba* and the opistobranch *Retusa obtusa* dominated in the most enclosed stations inside the harbour where sediments contained very high values of organic matter, lipids, and heavy metals. The data of the present study might assist in the building of new harbours in the future.

Heath, R. 1992. Nutrient dynamics in Great Lakes coastal wetlands: Future directions. *Journal of Great Lakes Research* 18:590-602.

Author Abstract. The most comprehensive investigations of N and P dynamics in Great Lakes coastal wetlands have been done at Old Woman Creek National Estuarine Research Reserve (OWC); whether OWC is a good general model of coastal freshwater wetlands remains to be shown. This wetland is probably a nutrient sink, storing P in sediments (at least temporarily) and releasing N by dissimilatory denitrification. Also, its biotic community transforms dissolved inorganic N and P inputs into organic dissolved and particulate outputs, thereby altering nutrient availability to Lake Erie communities. Nutrient dynamics in coastal wetlands probably differs greatly from that of inland marshes (where slow decomposition rates permit peat to accumulate as a nutrient sink) and estuaries (where high salinity alters sediment nutrient dynamics). A conceptual model specific for coastal wetlands is presented that accounts for the wide range of redox potentials encountered over the short vertical span of the shallow OWC wetland ecosystem. Future studies need to be conducted within the context of testable hypotheses generated from this model. Future investigations should focus attention on annualized nutrient budgets, sediment-water nutrient exchanges and their dependence on organic matter generated within the ecosystem.

Kennish, M. 2000. Ecology of Estuaries. Volume I: Physical and Chemical Aspects. CRC Press, Inc., Baca Raton, FL.

Editors Comments. Nearly all estuaries are characterized by highly variable physical and chemical conditions, which impose substantial physiological demands on populations that inhabit them. Consequently, successful organisms must have a broad tolerance in their requirements. Salinity gradients are typically large in estuaries from fresh water of rivers entering at their head to seawater of the nearshore ocean entering at their mouth. For some dissolved components, including oxygen, the nutrient elements nitrogen, phosphorus, and silicon, as well as many of the transition metals, spatial and temporal fluctuations in concentrations can be substantial. Seafloor sediments, in particular, show pronounced changes in certain physical-chemical parameters with increasing depth, such as redox potential (Eh), and oxygen depletion is usually rapid in near-surface layers. Physical factors – temperature, light, turbidity, currents, and wave action also vary abruptly in most estuarine systems.

Both salinity and temperature influence the density of estuarine waters, salinity more so than temperature. Density differences, in turn, drive water circulation and mixing processes. Wind-induced circulation is variable or intermittent. Interactive factors contribute to the complex circulation patters unique to estuaries.

Tides and tidal currents displace substantial volumes of water; both are modified extensively in estuaries compared with their properties in deeper oceanic waters. When resonance takes place between the tidal period of oscillation of an estuary, for example, tides and tidal currents increase in magnitude, sometimes by a large factor. The shoreline and bottom likewise strongly affect tidal currents by obstructing or constricting water flow, thereby altering circulation patterns. The release of energy from tidal currents transports sediments and various life-history stages of organisms and exerts forces on natural and manmade structures.

Llansó, R.J., L. C. Scott and F.S. Kelley. 2001. Chesapeake Bay water/quality monitoring program: Long-term benthic monitoring and assessment component level I comprehensive report. 82 pp. *Prepared by* Versar, Inc., 9200 Rumsey Road, Columbia, Maryland 21045, for Maryland Department of Natural Resources, Resource Assessment Service, Tidewater Ecosystem Assessments, Annapolis, MD.

Author Abstract. Benthic macroinvertebrates have been an important component of the State of Maryland's Chesapeake Bay water quality monitoring program since the program's inception in 1984. Benthos integrate temporally variable environmental conditions and the effects of multiple types of environmental stress. They are sensitive indicators of environmental status. Information on the condition of the benthic community provides a direct measure of the effectiveness of management actions. This report is the 18th in a series of annual reports that summarize data up to the current sampling year. Benthic community condition and trends in the Chesapeake Bay are assessed for 2001 and compared to results from previous years. A study to develop area-based restoration goals in relation to dissolved oxygen levels is included in this report.

McCall, P.L. and M.J.S. Tevesz (Eds). 1982. Animal-Sediment Relations: The Biogenic Alteration of Sediments. Plenum Press, New York.

The most extensive record available for the reconstruction of life on earth over the past seven hundred million years is preserved in ancient rocks and sediments on the bottom of rivers, lakes, and oceans. The interaction between the benthos – organisms that dwell on the bottom – and the sediment in which they live produces complex changes that affect the nature of the sediment, the sedimentary processes, and the ecology of all marine and freshwater environments. Benthic organisms burrow in the sediment for shelter and ingest it in search of food, causing changes in the composition of the sediment already deposited. The sedimentary bottoms act alternately as sources and sinks of nutrient elements and toxic materials; the sediment itself can become a major pollutant when suspended by waves and currents. This volume is the result of recent study of the nature of animal-sediment relations.

Matisoff, G. and J.P. Eaker. 1992. Summary of sediment chemistry research at Old Woman Creek, Ohio. *Journal of Great Lakes Research* 18:603-621.

Sediments are important at Old Woman Creek National Estuarine Research Reserve (OWC) and similar environments because suspended sediments provide a medium for the transport of many nutrients and toxic substances and bottom sediments may serve as either a sink or source of these substances, can influence estuarine productivity and water quality, can serve as substrates for much of the wetlands microscopic and macroscopic flora and fauna, and can contain a record of past conditions at the depositional site. Previous research at OWC has determined that the major sources of sediment supplied to the estuary are from soils and tills and the Berea Sandstone in the drainage basin. These sediments and their associated chemical species are primarily delivered to the estuary during storm events and the majority of the suspended sediment that washes into OWC is trapped and accumulates at the bottom of the estuary. Some postdepositional mobilization and sediment-water exchange of metals such as cadmium (downcore transport) and nutrients such as silica (release from sediments) has been observed and fluxes calculated. Groundwater seepage into the estuary varies with annual rainfall and is greatest near the estuary perimeter. Solute fluxes resulting from groundwater seepage are generally small compared to total fluxes as measured using bottom chambers. Benthic macroinvertebrates may contribute significantly to internal recycling. Both field measurements and computer simulations indicate that the water and solute budgets are controlled, in part, by a barrier sandbar which sometimes separates the estuary from Lake Erie.

Montagna, P. A., R. D. Kalke and C. Ritter. 2002. Effect of restored freshwater inflow on macrofauna and meiofauna in Upper Rincon Bayou, Texas, USA. *Estuaries* 25:1436-1447.

Author Abstract. Construction of two dams in 1958 and 1982 reduced freshwater inflow events to Rincon Bayou, part of the Nueces Delta near Corpus Christi, Texas, USA. Inflow reduction led to a reverse estuary, where low-salinity water flooded the delta on incoming tides and higher salinities were found near the Nueces River. Hypersaline conditions caused by high evaporation rates and low water levels were common during summer in the upper reaches. In October 1995, an overflow diversion channel was created by lowering the bank of the Nueces River to restore inflow events into the Rincon Bayou, which is the main stem creek that runs through the center of the Delta. Hypersaline conditions occurred four times from mid-1994 to mid-1997 and only once after mid-1997. Lower, rather than higher, salinity conditions were found after August 1997 in the upper reaches. Benthic faunal recovery was monitored by changes in macrofauna and meiofauna communities. Macrofauna responded to inflow events with increased abundances, biomass, and diversity but decreased during hypersaline conditions. Meiofauna abundance also increased with increasing inflow. Benthic characteristics were different in Rincon Bayou than in the reference site, upstream from introduced inflow. As inflow events have increased due to the diversion, the opportunities for positive responses to increased flow have increased. Although the overflow channel was filled in at the end of the demonstration project in the fall 2000, the City of Corpus Christi reopened the channel in the fall 2001 because the ecological benefits were credited toward the state-mandated minimum flow requirements for the Nueces Estuary.

Olafsson, E. 2003. Do macrofauna structure meiofauna assemblages in marine soft-bottoms? A review of experimental studies. *Vie et Milieu-Life and Environment* 53:249-265.

Author Abstract. During the past three decades a considerable number of studies have been conducted to reveal effects of macrofauna on meiofaunal assemblages in marine soft-bottoms. The aim of this review is to compile and summarize major findings of studies that have experimentally tested if a given macrofauna species affects some aspect of a meiobenthic assemblage. Altogether 77 studies on 44 macrofaunal species are reviewed. The bulk of the macrofaunal species are conspicuous members of the phyla Crustacea, Annelida and Mollusca, namely 20, 9 and 8 species respectively. Almost all the studies (86%) investigating biogenic structures of macrobenthos indicate some sort of effects on meiofaunal assemblages. Those studies in which diversity of a particular animal group has been considered, almost all agree on enhanced species diversity as a result of biogenic structures. The results of studies that have considered overall effects of macrofauna originating from processes such as predation, physical disturbance, competition for food and biogenic structures also indicate effects on meiobenthos. In only a few studies, researchers have used 3 or more density levels of disturbing macrofauna in their experimental manipulations, including natural levels, for the understanding of ecological rules behind biological disturbances. As biological disturbance created by macrofauna is incredibly variable among species and difficult to rate or categorise, it seems as yet difficult to apply theories to macrofaunal disturbance in general, predicting diversity or abundance patterns in meiofaunal assemblages.

Palmer, T. A., P. A. Montagna and R. D. Kalke. 2002. Downstream effects of restored freshwater inflow to Rincon Bayou, Nueces Delta, Texas, USA. *Estuaries* 25:1448-1456.

Author Abstract. In 1958 and 1982, two dams were built on the Nueces River that impeded freshwater flow to the Nueces Delta marsh. The result was the formation of a reverse estuary where salinity levels increased upstream instead of downstream as they would in a normal estuary. In 1995, channels were dug to restore freshwater flow to the marsh. Benthic organisms were monitored after the channels were dug to assess the effect of the change in hydrology. Results showed that freshwater pulses in the fall increased benthic productivity in the upper reaches of the restored area. The effect, however, only occurs in the fall when rain events are more frequent and flows of freshwater at other times of the year are too low to maintain freshwater conditions in the upper reaches of the estuary. The resulting wide ranges in salinity restricted the upper reaches of the marsh to short-lived, pioneer benthic species. Downstream areas of the marsh that exhibited smaller ranges in salinity levels had more diverse benthic communities.

Peterson, C.H., H.C. Summerson, E. Thomson, H.S. Lenihan, J. Grabowski, L. Manning, F. Micheli and G. Johnson. 2000. Synthesis of linkages between benthic and fish communities as a key to protecting essential fish habitat. *Bulletin of Marine Science* 66: 759-774.

Author Abstract. Several essential fish habitats lack the protections necessary to prevent degradation because of failure to integrate the scientific disciplines required to understand the causes of the degradation and failure to integrate the fragmented state and federal management authorities that each hold only a piece of the solution. Improved protection of essential habitat for demersal fishes requires much better synthesis of benthic ecology, fisheries oceanography, and traditional fisheries biology. Three examples of degraded habitat for demersal fishes and shellfishes are high-energy intertidal beaches, subtidal oyster reefs, and estuarine soft bottoms. In each case, both scientific understanding of and management response to the problem require a holistic approach. Intertidal beach habitat for surf fishes could be protected by constraints on the character of sediments used in beach nourishment and restriction of nourishment activity to biologically inactive seasons. Subtidal oyster-reef habitat for numerous crabs, shrimps, and finfishes could be protected and restored by reduction of nitrogen loading to the estuary and elimination of dredge damage to reefs. Estuarine soft-bottom habitat for demersal fin- and shellfishes could also be protected by reduction of the nutrient loading of the estuary, which could prevent associated problems of nuisance blooms and low dissolved oxygen. Although a broad general understanding of the nature of habitat degradation exists for each of these three examples, the interdisciplinary science needed to sort out the separate and interactive contributions of all major contributing factors is incomplete. Adopting the holistic approach embodied in the principles of ecosystem management sets a course for addressing both the scientific inadequacies and the management inaction.

Pickrill, R.A. and B.J. Todd. 2002. Sea floor mapping on the Scotian Shelf and the Gulf of Maine: Implications for the management of ocean resources. Symposium on the Effects of Fishing Activities on Benthic Habitats: Linking Geology, Biology, Socioeconomics, and Management. Tampa, FL. November 12-14, 2002.

Author Abstract. Multibeam sea floor mapping technologies have provided the capability to accurately, and cost effectively, image large areas of the seabed. Imagery provides base maps of sea floor topography from which targeted surveys can be planned to map sea floor sediments and associated benthic communities. Over the last five years extensive multi-disciplinary surveys have been carried out on Browns, German, and Georges Banks. The government of Canada entered into a partnership with the scallop industry to map bathymetry, surficial sediments and benthic communities. The new knowledge has been used by industry, and has implications for fisheries management. Associations between substrate type and benthic community composition have enabled precise maps of scallop habitat to be produced and links between scallop abundance and substrate to be established. The environmental and economic benefits have been immediate, with reduced effort to catch set quota, less bottom disturbance, and containment of fishing activity to known scallop grounds. Stock assessments and management practices are improved. Other pilot projects in Atlantic Canada and the northeastern USA have demonstrated the value of integrated sea floor mapping in designating marine protected areas (The Gully, Stellwagen Bank), in identifying offshore hazards such as landslides, in siting offshore structures, cables and pipelines, and in addressing environmental issues such as the routing of outfalls and disposal of dredge materials. In recognition of the power of these new tools and digital map products, Canada is considering development of a national mapping strategy to provide the foundation for sustainable ocean management in the 21st century.

Tung J. T. and P.A. Tanner 2003. Instrumental determination of organic carbon in marine sediments. *Marine Chemistry* 80:161–170

Author Abstract. Methodology is presented for the first completely instrumental determination of organic carbon (OC) in marine sediments, using a carbon–hydrogen–nitrogen (CHN) analyzer for total carbon (TC) content and diffuse reflectance infrared Fourier transform spectroscopy (DRIFTS) for in organic carbon IC) content. It utilizes direct calibration or standard addition in quantifying the carbonate combination and intensity at the energy near 2510 cm^{-1}. Since no OC standard reference materials are currently available, we have compared the results for OC from the proposed method with those from more tedious methods, involving wet chemistry. No significant difference was found with determinations, employing the CHN analyzer together with acid-extract analyses by (i) an inductively coupled plasma atomic emission spectrometer (ICP-AES) and (ii) a dissolved organic carbon (DOC) solution analyzer, with the decarbonation mass change being taken into account for the method (ii) involving acid addition. The proposed DRIFTS method is cheap, rapid, and nondestructive.

Vos, J.H., P.J. Van den Brink, E.P. Van den Ende, M.A.G. Ooijevaar, A.J.P. Oosthoek, J.F. Postma and W. Admiraal. 2002. Growth response of a benthic detritivore to organic matter composition in sediments. *Journal North American Benthological Society* 21:443-456.

Author Abstract. The biochemical composition of lake and stream sediments was analyzed and compared to growth and survival of detritivorous larvae of the midge *Chironomus riparius* (Meigen) to determine which biochemical parameters correlated most strongly with sediment food quality. Sediments were collected from soft bottoms of 41 water systems and fed to midge larvae. These sediments were analyzed for organic matter (OM) content, total C, N, and P, carbohydrates, proteins, fatty acids, pigments, and grain-size distribution. A microbial assay was used as an indicator of the fraction of easily biodegradable OM. Positive correlations of larval growth or survival with polyunsaturated fatty acids, pigments, and labile OM were found when these biochemical variables were standardized based on dry mass. When variables were standardized based on mass of OM, additional significant positive correlations between larval growth and P, carbohydrates, proteins, and fatty acids of bacterial origin were detected. Similarly, multivariate analyses revealed stronger correlations between larval growth and survival and biochemical variables standardized by OM compared to those standardized by dry mass. We postulate that dilution of OM by mineral particles caused the difference between the standardization methods. Organic matter content of sediments, particularly labile organic matter, appeared to strongly influence detritivore growth.

APPENDIX II: SOFT BOTTOM HABITATS
REVIEW OF TECHNICAL METHODS MANUALS

This Review of Technical Methods Manuals includes a variety of sampling manuals, Quality Assurance/Quality Control (QA/QC) documents, standardized protocols, or other technical resources that may provide practitioners with the level of detail needed when developing a monitoring plan for a coastal restoration project. Entries were selected through extensive literature and Internet searches as well as input from reviewers. As with the Annotated Bibliographies, these entries are not, however, a complete list. Entries are arranged alphabetically. Wherever possible, web addresses or other contact information is included in the reference to assist readers in easily obtaining the original resource. Summaries preceded by the terms '*Author Abstract'* or *'Publisher Introduction*' or similar descriptors were taken directly from their original source. Summaries without such descriptors were written by the authors of the associated chapter.

American Public Health Association. 1998. Standard Methods for Examination of Water & Wastewater. 20th ed. American Public Health Association, Washington, D.C.

Standard Methods for Examination of Water and Wastewater is an essential resource for any laboratory performing analysis on water samples whether they be for chemical or biological components. Procedures for the sampling of zooplankton, phytoplankton, periphyton, macrophytes, benthic macroinvertebrates, and fish are included as well as general identification keys to these organisms. Each procedure is explained in step-by-step detail with information on the strengths and weaknesses of various measurement methods. To a general practitioner, this resource would be useful to explain the chemical and biological components they are sampling, what the analysis entails, and the meaning of the final value obtained from each type of analysis. Various editions should be available at most any laboratory, scientific, or university library.

Bruce Thompson B., S. Lowe and M. Kellogg. 2000. San Francisco Estuary regional monitoring program for trace substances results of the benthic pilot study1994-1997: part 1–macrobenthic assemblages of the San Francisco Bay-Delta, and their responses to abiotic factors, 39 pp. San Francisco Estuary Regional Monitoring Program for Trace Substances Technical Report 39.

Author Abstract. The Benthic Pilot Study began in 1994 because the original RMP Base Program did not include any *in situ* biological indicators of contaminant effects, and such information was considered to be an important component of Bay assessments. Benthic sampling is a common component of most coastal and aquatic monitoring programs in the US. Benthos are monitored because they are a key component of the ecosystem that links sediments to the aquatic food web and provides food for bottom feeding fish and birds. Benthic organisms facilitate other important sediment functions, such as nutrient and carbon flux, by their burrowing and feeding activities. Most infaunal organisms are not very motile and must respond to a variety of natural environmental factors including changes in salinity, turbidity, and dissolved oxygen. Thus, benthos are considered to be reliable indicators of local sediment conditions. Understanding benthic responses to natural environmental fluctuations is essential before assessment of effects from anthropogenic factors (e.g., diversions of freshwater inflows, dredging, contamination, of introduced species) can be made.

The objective of the Benthic Pilot Study was to evaluate the use of benthic information for determining environmental conditions in the Estuary. The results of the RMP Benthic Pilot Study are reported in two Parts. Part 1 describes the distribution of the benthic assemblages identified in the Bay and Delta, the species composition and abundances of these assemblages, and shows the influences of variable Delta outflow, salinity, and sediment-type on them. The Benthic Pilot Study was a collaborative study including data from the RMP, Department of Water Resources, Bay Area Discharger's Association, and the Bay Protection and Toxic Clean-up Program.

Environment and Natural Resources Institute. 2002. Quality assurance project plan, 59 pp. Alaska Biological Monitoring and Assessment Program, Anchorage, AK. http://www.uaa.alaska.edu/enri/bmap/pdfs/ENRI_QAPP_2-02.pdf

This quality assurance project plan (QAPP) is designed for use in collecting data to assess wadable streams in Alaska focusing on the collection of benthic invertebrates and chemical water quality parameters. It can be used by practitioners restoring and monitoring other coastal habitats as a template of the types of information and level of detail required for a QAPP. QAPPs are important documents for any monitoring effort to have readily available. They are used by to ensure that data are collected in a comparable and consistent fashion regardless of who is obtaining the sampling. Some of the topics included in this QAPP include the identification of responsible parties; procedures for properly selecting sample locations and reference conditions; the collection, handling, and preservation of biological and chemical samples; methods to analyze samples and record data; data management; contingency plans for foreseeable mistakes and accidents; and methods to verify and validate the accuracy of data. Example data sheets and procedures for using specific types of equipment are also included.

Folk, R.L. 1980. The Petrology of Sedimentary Rocks. Walter Geology Library, Web Version 1.0. http://www.lib.utexas.edu/geo/FolkReady/folkprefRev.html

This paper is an out-of-print classic in the field of sedimentary rocks and the interpretation of grain size. For estuary and wetland restoration, the important chapters are on properties of sedimentary rocks and the collection and preparation of samples for analysis.

Gibbons, W.N., M.D. Munn and M.D. Paine. 1993. Guidelines for monitoring benthos in freshwater environments, 81 pp. Report prepared for Environment Canada, North Vancouver, B.C. by EVS Consultants, North Vancouver, B.C.

Historically, benthic invertebrates have been viewed as useful organisms for evaluating environmental impacts on aquatic systems (freshwater and marine) (Klemm et al., 1990; Rosenberg and Resh, 1993). They are relatively sedentary organisms, and are sensitive to changes in sediment and water quality. Benthic communities also reflect the cumulative effects of present and past conditions, because they have low mobility and life cycles of several weeks to years (Wilhm, 1975). Their ecological relationships are relatively well understood (Herricks and Cairns 1982), and they are the major food source for many fish species. For these reasons, sampling benthic communities is regarded as a cost-effective means of assessing the aquatic environment. Although benthos monitoring programs have been conducted for decades (Cairns and Pratt, 1993), in Canada there has been little effort to standardize the wide array of methods and approaches used.

As a first step in achieving standardization, Environment Canada and EVS Consultants hosted a technically-based workshop on benthos monitoring (Gibbons and Booth 1992) to attempt to develop a consensus on the approach to be used when undertaking benthic invertebrate studies (as an environmental monitoring tool) in freshwater environments. The document represents the first stage in the development of a protocol for freshwater benthos monitoring for the purpose of environmental assessment.

Llanso, R.J., L.C. Scott, D.M. Dauer, J.L. Hyland and D.E. Russell. 2002. An estuarine benthic index of biotic integrity for the Mid-Atlantic region of the United States. I. Classification of assemblages and habitat definition. *Estuaries* 25:1219-1230.

Author Abstract. An objective of the Mid-Atlantic Integrated Assessment Program (MAIA) of the U.S. Environmental Protection Agency is to develop an index for assessing benthic community condition in estuaries of the mid-Atlantic region of the United States (Delaware Bay through Pamlico Sound). To develop such an index, natural unimpaired communities must first be identified and variability related to natural factors accounted for. This study focused on these two objectives; Llanso et al. (2002) describe the index. Using existing data sets from multiple years, classification analyses of species abundance and discriminant analysis were employed to identify major habitat types in the MAIA region and evaluate the physical characteristics that structure benthic infaunal assemblages. Sampling was restricted to soft bottoms and to the, index development period, July through early October. The analyses revealed salinity and sediment composition as major factors structuring infaunal assemblages in mid-Atlantic estuaries. Geographical location was a secondary factor. Nine habitat classes were distinguished as a combination of 6 salinity classes, 2 sediment types, and the separation of North Carolina and Delaware-Chesapeake Bay polyhaline sites. The effect of sediment types on faunal assemblages was restricted to polyhaline sites, which were separated into two sediment groups above and below 90% sand content. Assemblages corresponding to each of these 9 habitats were identified in the context of widely recognized patterns of dominant taxa. Differences between North Carolina and Delaware-Chesapeake Bay polyhaline assemblages were attributed to the relative contributions of species and not to differences in species composition. No zoogeographic discontinuities could be identified. Our results reinforce the findings of recent studies which suggest that, with respect to estuarine benthic assemblages, the boundary between the Virginian and the Carolinian Provinces be moved to a new location south of Pamlico Sound.

Merritt, R. W. and K. W. Cummins, (eds.). 1996. An Introduction to the Aquatic Insects of North America. Third edition ed. Kendall/Hunt Publishing Company, Dubuque, IA, USA.

While the bulk of Merritt and Cummins is on identification of aquatic insects of North America, they include several chapters useful in project planning as well. Various experts in the field of aquatic insect collection and identification have submitted chapters on: the general morphology of aquatic insects, designing studies, collection techniques, aquatic insect respiration, habitat and life history, and the ecology and distribution of aquatic insects. The rest of the manual is devoted to identification keys for each family of aquatic insect found in North America with many detailed and useful pictures of identifying characteristics.

Since this book is continental in scope, it is suggested that practitioners first look for identification keys prepared for their local or regional waterways. This will reduce much confusion in the identification process by eliminating species that are not found locally. Any local aquatics expert or science librarian should be able to locate these materials. If local materials are not available, then Merritt and Cummins will be useful, however, be sure to check the distribution of species identified whenever possible.

Polhe, G.W. and M.L.H. Thomas. 2001. Monitoring protocol for marine benthos: Intertidal and subtidal macrofauna. 32 pp. A report by the Marine Biodiversity Monitoring Committee (Atlantic Maritime Ecological Science Cooperative, Huntsman Marine Science Centre) to the Ecological Monitoring and Assessment Network of Environment Canada, Environment Canada, St. John's, Newfoundland, Canada. http://www.eman-rese.ca/eman/ecotools/protocols/marine/benthics/intro.html

This report recommends guidelines for sampling, sample processing, and data analysis of marine benthos to establish uniformity in procedures that will make data from different investigations more readily comparable. Decisions on the methodology, equipment and analysis will depend on the particular aims of a study, on the nature of the habitat involved, on the staff and facilities available, and on historical or personal preferences. The report consideration is limited to the inter- and subtidal zoobenthos macrofauna, comprising the burrowing fauna (infauna) and surface living fauna (epifauna) retained in a 0.5 mm mesh, and excluding the smaller interstitial meiofauna (small metazoans), microfauna (protozoans and organisms of bacteria size) and the phytobenthos which all require special techniques.

Poppe, L.J., A. H. Eliason, J. J. Fredericks, R. R. Rendigs, D. Blackwood and C. F. Polloni. 2000, Grain-size analysis of marine sediments: methodology and data processing: U.S. Geological Survey Open-File Report 00-358. http://pubs.usgs.gov/of/of00-358/text/contents.htm

Grain size is the most fundamental physical property of sediment. Geologists and sedimentologists use information on sediment grain size to study trends in surface processes related to the dynamic conditions of transportation and deposition; engineers use grain size to study sample permeability and stability under load; geochemists use grain size to study kinetic reactions and the affinities of fine-grained particles and contaminants; and hydrologists use it when studying the movement of subsurface fluids. Therefore, with these reasons in mind, the objectives of a grain-size analysis are to accurately measure individual particle sizes or hydraulic equivalents, to determine their frequency distribution, and to calculate a statistical description that adequately characterizes the sample.

The techniques and equipment used for particle-size analysis must be fast, accurate, and yield highly reproducible results. The accuracy of these measurements is limited by sampling techniques, storage conditions, analytical methods, equipment, and, especially, the capability of the operator. Care and attention to detail must be exercised to achieve the best possible results. As with most types of sedimentological analyses there is no ultimate technique or procedure that will produce the most desirable grain size data for all cases. Several types of analyses have been developed over the years to accommodate the different types and sizes of samples and the reasons for conducting the analysis

Rosenberg, D. M., I. J. Davies, D. G. Cobb and A. P. Wiens. 2001. Protocols for measuring biodiversity: benthic macroinvertebrates in fresh waters. Ecological Monitoring and Assessment Network Coordinating Office, Knowledge Integration Directorate of Environment Canada. http://www.eman-rese.ca/eman/ecotools/protocols/freshwater/benthics/intro.html

Partial Author Introduction: The collection of benthic macroinvertebrates from lakes and streams is usually a straightforward procedure using standard equipment. However, the removal of organisms from background material can be tedious and time-consuming unless available labor-saving strategies are used (see below) and the identification of organisms to the species level, when possible, requires substantial training and skill. The processing of samples can be successfully accomplished by non-specialists, but the involvement of systematists is recommended for species-level identifications. Data-analysis procedures are standard, and can be done by anyone trained in elementary statistics. The following account describes sampling methods for benthic macroinvertebrates in lotic (stream) and lentic (lake) habitats, valuable ancillary information, different analytical paths to follow, and techniques for efficient operation in the field and laboratory.

U.S. EPA. 1987. Recommended protocols for sampling and analyzing subtital benthic macroinvertebrate assemblages in Puget Sound. U.S. Environmental Protection Agency Region 10 Office of Puget Sound and Puget Sound Water Quality Authority. http://www.psat.wa.gov/Publications/protocols/protocol_pdfs/benthos.pdf

Recommended methods for sampling and analyzing subtidal soft-bottom benthic macroinvertebrate assemblages in Puget Sound are presented in this chapter. The methods are based on the results of a workshop and written reviews by representatives from most organizations that fund or conduct environmental studies in Puget Sound. The purpose of developing these recommended protocols is to encourage all Puget Sound investigators conducting monitoring programs, baseline surveys, and intensive investigations to use standardized methods whenever possible. If this goal is achieved, most data collected in the Sound should be directly comparable, and thereby capable of being integrated into a sound-wide database. Such a database is necessary for developing and maintaining a comprehensive water quality management program for Puget Sound.

Before the recommended protocols are described, a section is presented on study design considerations. This section discusses some major elements of the design of subtidal benthic macroinvertebrate studies that were considered at the workshop but left unresolved. Following this initial section, specifications are provided for the field, laboratory, quality assurance/quality control (QA/QC), and data reporting procedures that are recommended for most future benthic macroinvertebrate studies in Puget Sound.

U.S. EPA. 2001. Methods for collection, storage, and manipulation of sediments for chemical and toxicological analyses: technical manual, EPA/823/B-01/002. Office of Water. http://www.epa.gov/waterscience/cs/collection.html

It is now widely known that the methods used in sample collection, transport, handling, storage, and manipulation of sediments and interstitial waters can influence the physicochemical properties and the results of chemical, toxicity, and bioaccumulation analyses. Addressing these variables in an appropriate and systematic manner will help assure more accurate sediment quality data and facilitate comparisons among sediment studies.

This Technical Manual provides current information and recommendations for collecting and handling sediments for physicochemical characterization and biological testing, using procedures that are most likely to maintain *in situ* conditions, most accurately represent the sediment in question, or satisfy particular program needs, to help ensure consistent, high quality data collection

U.S. EPA. 2001. National coastal assessment: field operations manual. EPA 620/R-01/003, 72 pp., U. S. Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Gulf Ecology Division, Gulf Breeze, FL. http://www.epa.gov/emap/nca/html/docs/c2kfm.pdf

This manual presents a standard set of field data and sample collection techniques for the EPA's National Coastal Assessment, the current state of the EPA's Environmental Assessment Program (EMAP). Though the methods collected here are geared specifically toward this program, some restoration practitioners may find them useful particularly in areas where restoration projects overlap existing monitoring activities, as this will facilitate the comparison of current data with historic trends. The measurement protocols described in this manual include:

- sediment contaminant concentrations
- sediment toxicity
- benthic species composition
- sediment characteristics
- water column dissolved nutrients
- chlorophyll *a* concentrations
- total suspended solids
- surface and bottom dissolved oxygen, salinity, temperature, and pH
- water clarity
- contaminant levels in fish and shellfish
- external pathological condition of fish
- fish community structure

A suggested monitoring routine is presented for data collection at each site to maximize sampling efficiency while in the field. Of particular use to the beginning restoration-monitoring practitioner, a list of necessary field and laboratory equipment is also provided in an appendix.

U.S. EPA. 2001. Volunteer Estuary Monitoring: A Methods Manual. United States Environmental Protection Agency, Office of Water. http://www.epa.gov/owow/estuaries/monitor/

Partial author abstract. This document presents information and methodologies specific to estuarine water quality. The first eight chapters of the manual deal with typical issues that a new or established volunteer estuary monitoring program might face:

- understanding estuaries, what makes them unique, the problems they face, and the role of humans in solving the problems
- establishing and maintaining a volunteer monitoring program
- working with volunteers and making certain that they are well-positioned to collect water quality data safely and effectively
- ensuring that the program consistently produces data of high quality, and
- managing the data and making it available to data users

The remaining chapters focus on several water quality parameters that are important in determining the health of an estuary. These chapters are divided into three units, which characterize the parameters as measures of the chemical, physical, or biological environment of the estuary.

The significance of each parameter and specific methods to monitor it are detailed in a step-by-step fashion. The manual stresses proper quality assurance and quality control techniques to ensure that the data are useful to state agencies and any other data users.

References are listed at the end of each chapter. Appendices containing additional resources are also supplied. These references should prove a valuable source of detailed information to anyone interested in establishing a new volunteer program or a background resource to those with already established programs.

APPENDIX III: LIST OF SOFT BOTTOM HABITAT EXPERTS

The expert listed below has provided his contact information so practitioners may contact him with questions pertaining to the restoration or restoration monitoring of this habitat. Contact information is up-to-date as of the printing of this volume. The list below includes only those experts who were 1) contacted by the authors and 2) agreed to submit their contact information. In addition to this resource, practitioners are encouraged to seek out the advice of local experts as well faculty members and researchers at colleges and universities. Engineering, planning, and landscape architecture firms also have experts on staff or contract out the services of botanists, biologists, ecologists, and other experts whose skills are needed in restoration monitoring. These people are in the business of providing assistance in restoration and restoration monitoring and are often extremely knowledgeable in local habitats and how to implement projects on the ground. Finally local, state, and Federal environmental agencies also house many experts who monitor and manage coastal habitats. In addition to the National Oceanic and Atmospheric Administration (NOAA), the Environmental Protection Agency (EPA), the Army Corps of Engineers (ACE), Fish and Wildlife Service (FWS), and the United States Geologic Survey (USGS) are important Federal agencies to contact for assistance in designing restoration and monitoring projects as well as potential sources of funding and permits to conduct work in coastal waterways.

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GLOSSARY

Abiotic - non-living

Adaptive management - a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form–"active" adaptive management–employs management programs that are designed to experimentally compare selected policies or practices, by evaluating alternative hypotheses about the system being managed.

Aerobic - (of an organism or tissue) requiring air for life; pertaining to or caused by the presence of oxygen

Algae - simple plants that are very small and live in water through photosynthesis, algae are the main producers of food and oxygen in water environments

Allochthanous - carbon that is formed outside of a particular area as opposed to an autochthanous carbon that is produced within a given area

Alluvial plain - the floodplain of a river, where the soils are alluvial deposits carried in by overflowing river

Alluvium - any sediment deposited by flowing water, as in a riverbed, floodplain, or delta

Alternate hypothesis - a statement about the values of one or more parameters usually describing a potential change

Anaerobic - living in the absence of air or free oxygen; pertaining to or caused by the absence of oxygen

Anoxic - without oxygen

Anthropogenic - caused by humans; often used when referring to human induced environmental degradation

Apical - the tips of the plants

Aquatic - living or growing in or on water

Asset mapping - a community assessment research method that provide a graphical representation of a community's capacities and assets

Assigned values - the relative importance or worth of something, usually in economic terms. Natural resource examples include the value of water for irrigation or hydropower, land for development, or forests for timber supply (see held values).

Attitude - an individual's consistent tendency to respond favorably or unfavorably toward a given attitude object. Attitudes can be canvassed through survey research and are often defined utilizing scales ranging from positive to negative evaluations.

Backwater - a body of water in which the flow is slowed or turned back by an obstruction such as a bridge or dam, an opposing current, or the movement of the tide

Baseline measurements - a set of measurements taken to assess the current or pre-restoration condition of a community or ecosystem

Basin morphology - the shape of the earth in the area a coastal habitat is found

Benefit-cost analysis - a comparison of economic benefits and costs to society of a policy, program, or action

Benthic - on the bottom or near the bottom of streams, lakes, or oceans

Bequest value - the value that people place on knowing that future generations will have the option to enjoy something

Biogenic - produced by living organisms

Biomass - the amount of living matter, in the form of organisms, present in a particular habitat, usually expressed as weight- per-unit area

Blackwater streams - streams that do not carry sediment, are tannic in nature and flow through peat-based areas

Brackish - water with a salinity intermediate between seawater and freshwater (containing from 1,000 to 10,000 milligrams per liter of dissolved solids)

Calcareous - sediment/soil formed of calcium carbonate or magnesium carbonate due to biological deposition or inorganic precipitation

Canopy formers - plants that form a diverse vertical habitat structure

Carnivores - organisms that feed on animals

Catchment - the land area drained by a river or stream; also known as “watershed” or “drainage basin”; the area is determined by topography that divides drainages between watersheds

Causality - or causation, refers to the relationship between causes and effects: i.e., to what extent does event ‘A’ (the cause) bring about effect ‘B’

Coastal habitat restoration - the process of reestablishing a self-sustaining habitat in coastal areas that in time can come to closely resemble a natural condition in terms of structure and function

Coastal habitat restoration monitoring - the systematic collection and analysis of data that provides information useful for measuring coastal habitat restoration project performance

Cognitive mapping - a community assessment research method used to collect qualitative data and gain insight into how community members perceive their community and surrounding natural environment

Cohort studies - longitudinal research aimed at studying changing in a particular subpopulation or cohort (e.g., age group) over time (see longitudinal studies)

Community - all the groups of organisms living together in the same area, usually interacting or depending on each other for existence; all the living organisms present in an ecosystem

Community (human) - a group of people who interact socially, have common historical or other ties, meet each other’s needs, share similar values, and often share physical space; A sense of “place” shaped by either natural boundaries (e.g., watershed), political or administrative boundaries (e.g., city, neighborhood), or physical infrastructure

Computer-assisted telephone interviewing (CATI) - a system for conducting telephone survey interviews that allows interviewers to enter data directly into a computer database. Some CATI systems also generate phone numbers and dial them automatically.

Concept mapping - community assessment research method that collects data about how community members perceive the causes or related factors of particular issues, topics, and problems

Content validity - in social science research content validity refers to the extent to which a measurement (i.e., performance standard) reflects the specific intended domain of content (i.e., stated goal or objective). That is, how well does the performance standard measure whether or not a particular project goal has been met?

Contingent choice method - estimates economic values for an ecosystem or environmental service. Based on individual’s tradeoffs among sets of ecosystems, environmental services or characteristics. Does not directly ask for willingness to pay; inferred from tradeoffs that include cost as an attribute.

Contingent valuation method (CVM) - used when trying to determine an individual or individuals’ monetary valuation of a resource. The CVM can be used to determine changes in resource value as related to an increase or decrease in resource quantity or quality. Used to measure non-use attributes such as existence and bequest values; market data is not used.

Coral reefs - highly diverse ecosystems, found in warm, clear, shallow waters of tropical oceans worldwide. They are composed of marine polyps that secrete a hard calcium carbonate skeleton, which serves as a base or substrate for the colony.

Coralline algae - algae that contains a coral-like, calcareous outer covering

Cost estimate - estimates on costs of planning and carrying out a project. Examples of items that may be included in a cost estimate for a monitoring plan may be personnel, authority to provide easements and rights-of-way, maintenance, labor, and equipment.

Coulter counter - a device that measures the amount of particles in water

Coverage error - a type of survey error that can occur when the list – or frame – from which a sample is drawn does not include all elements of the population that researchers wish to study

Cross-sectional studies - studies that investigate some phenomenon by taking a cross section (i.e., snapshot) of it at one time and analyzing that cross section carefully (see longitudinal studies)

Crowding - in outdoor recreation, crowding is a form of conflict (see outdoor recreation conflict) that is based on an individual's judgment of what is appropriate in a particular recreation activity and setting. Use level is not interpreted negatively as crowding until it is perceived to interfere with one's objectives or values. Besides use level, factors that can influence perceptions of crowding include participant's motivations, expectations, and experience related to the activity, and characteristics of those encountered such as group size, behavior, and mode of travel.

Cryptofauna - tiny invertebrates that hide in crevices

Cultch - empty oyster shells and other materials that are on the ground and used as a place of attachment

Culture - a system of learned behaviors, values, ideologies, and social arrangements. These features, in addition to tools and expressive elements such as graphic arts, help humans interpret their universe as well as deal with features of their environments, natural and social.

Cyanobacteria - blue-green pigmented bacteria; formerly called blue-green algae

Dataloggers - an electronic device that continually records data over time

Deepwater swamps - forested wetlands that develop along edges of lakes, alluvial river swamps, in slow-flowing strands, and in large, coastal-wetland complexes. They can be found along the Atlantic and Gulf Coasts and throughout the Mississippi River valley. They are distinguished from other forested habitats by the tolerance of the dominant vegetation to prolonged flooding.

Demersal - bottom-feeding or bottom-dwelling fish, crustaceans, and other free moving organisms

Detritivorous - the practice of eating primarily detritus

Detritus - fine particles of decaying organic and inorganic matter fomed by excrement and by plant and animal remains; maybe suspended in water or accumulated on the bottom of a water body

Diatoms - any of a class (Bacillariophyceae) of minute planktonic unicellular or colonial algae with silicified skeletons that form shells.

Direct impacts - the changes in economic activity during the first round of spending. For tourism this involves the impacts on the tourism industries (businesses selling directly to tourists) themselves (see Secondary Effects)

Dissolved oxygen - oxygen dissolved in water and available to aquatic organisms; one of the most important indicators of the condition of a water body; concentrations below 5 mg/l are stressful and may be lethal to many fish and other species

Dominant species - a plant species that exerts a controlling influence on or defines the character of a community

Downwelling - the process of build-up and sinking of surface waters along coastlines

Driving forces - the base drivers that play a large role in people's decision making processes and influence human behavior. Societal forces such as population, economy, technology, ideology, politics and social organizations are all drivers of environmental change.

Duration - a span or interval of time

Ebb - a period of fading away, low tide

Echinoderms - any of a phylum (Echinodermata) of radially symmetrical coelomate marine animals including the starfishes, sea urchins, and related forms

Economic impact analysis - used to estimate how changes in the flow of goods and services can affect an economy. Measure of the impact of dollars from outside a defined region/area on that region's economy. This method is often used in estimating the value of resource conservation.

Ecosystem - a topographic unit, a volume of land and air plus organic contents extended aerially for a certain time

Ecosystem services - the full range of goods and services provided by natural ecological systems that cumulatively function as fundamental life-support for the planet. The life-support functions performed by ecosystem services can be divided into two groups: production functions (i.e., goods) and processing and regulation functions (i.e., services).

Emergent plants - water plants with roots and part of the stem submerged below water level, but the rest of the plant is above water; e.g., cattails and bulrushes

Environmental equity - the perceived fairness in the distribution of environmental quality across groups of people with different characteristics

Environmental justice - a social movement focused on the perceived fairness in the distribution of environmental quality among people of different racial, ethnic or socio-economic groups

Ephemeral - lasting a very short time

Epifaunal - plants living on the surface of the sediment or other substrate such as debris

Epiphytes - plants that grow on another plant or object upon with it depends for mechanical support but not as a source of nutrients

Estuary - a part of a river, stream, or other body of water that has at least a seasonal connection with the open sea or Great Lakes and where the seawater or Great Lakes water mixes with the surface or subsurface water flow, regardless of the presence of man-made structures or obstructions.

Eukaryotic - organisms whose cells have a nucleus

Eulittoral - refers to that part of the shoreline that is situated between the highest and lowest seasonal water levels

Eutrophic - designating a body of water in which the increase of mineral and organic nutrients has reduced the dissolved oxygen, producing an environment that favors plant over animal life

Eutrophication - a natural process, that can be accelerated by human activities, whereby the concentration of nutrients in rivers, estuaries, and other bodies of water increases; over time this can result in anaerobic (lack of oxygen) conditions in the water column; the increase of nutrients stimulates algae "blooms;" as the algae decays and dies, the availability of dissolved oxygen is reduced; as a result, creatures living in the water accustomed to aerobic conditions perish

Evapotranspiration - a term that includes water discharged to the atmosphere as a result of evaporation from the soil and surface-water bodies and by plant transpiration

Existence value - the value that people place on simply knowing that something exists, even if they will never see it or use it

Exotic species - plants or animals not native to the area

Fauna - animals collectively, especially the animals of a particular region or time

Fecal coliforms - any of several bacilli, especially of the genera *Escherichia*, found in the intestines of animals. Their presence in water suggests contamination with sewage of feces, which in turn could mean that disease-causing bacteria or viruses are present. Fecal coliform bacteria are used to indicate possible sewage contamination. Fecal coliform bacteria are not harmful themselves, but indicate the possible presence of disease-causing bacteria, viruses, and protozoans that live in human and animal digestive systems. In addition to the possible health risks associated with them, the bacteria can also cause cloudy water, unpleasant odors, and increased biochemical oxygen demand.

Fetch - the distance along open water or land over which the wind blows

Fishery dependent data - data on fish biology, ecology and population dynamics that is collected in connection with commercial, recreational or subsistence fisheries.

Flooding regime - pattern of flooding over time

Floodplain - a strip of relatively flat land bordering a stream channel that may be overflowed at times of high water; the amount of land inundated during a flood is relative to the severity of a flood event

Flora - plants collectively, especially the plants of a particular region or time

Fluvial - of, relating to, or living in a stream or river

Focus group - a small group of people (usually 8 to 12) that are brought together by a moderator to discuss their opinions on a list of predetermined issues. Focus groups are designed to collect very detailed information on a limited number of topics.

Food chain - interrelations of organisms that feed upon each other, transferring energy and nutrients; typically solar energy is processed by plants who are eaten by herbivores which in turn are eaten by carnivores: sun –> grass –> mouse –> owl

Food webs - the combined food chains of a community or ecosystem

Frequency - how often something happens

Fronds - leaf-like structures of kelp plants

Function - refers to how wetlands and riparian areas work – the physical, chemical, and biological processes that occur in these settings, which are a result of their physical and biological structure

Functional habitat characteristics - characteristics that describe what ecological service a habitat provides to the ecosystem

Gastropods - any of a large class (Gastropoda) of mollusks (as snails and slugs) usually with a univalve shell or none and a distinct head bearing sensory organs

Geomorphic - pertaining to the form of the Earth or of its surface features

Geomorphology - the science that treats the general configuration of the Earth's surface; the description of landforms

Habitat - the sum total of all the living and non-living factors that surround and potentially influence an organism; a particular organism's environment

Hard bottom - the floor of a water body composed of solid, consolidated substrate, including reefs and banks. The solid floor typically provides an attachment surface for sessile organisms as well as a rough three-dimensional surface that encourages water mixing and nutrient cycling.

Hedonic pricing method - estimates economic values for ecosystem or environmental services that directly affect market prices of some other good. Most commonly applied to variations in housing prices that reflect the value of local environmental attributes.

Held values - conceptual precepts and ideals held by an individual about something. Natural resource examples include the symbolic value of a bald eagle or the aesthetic value of enjoying a beautiful sunset (see assigned values).

Herbivory - the act of feeding on plants

Holdfasts - a part by which a plant clings to a flat surface

Human dimensions - an multidisciplinary/interdisciplinary area of investigation which attempts to describe, predict, understand, and affect human thought and action toward natural environments in an effort to improve natural resource and environmental stewardship. Disciplines within human dimensions research is conducted include (but are not limited to) sociology, psychology, resource economics, geography, anthropology, and political science.

Human dominant values - this end of the natural resource value continuum emphasizes the use of natural resources to meet basic human needs. These are often described as utilitarian, materialistic, consumptive or economic in nature.

Human mutual values - the polar opposite of human dominant values, this end of the natural resource value continuum emphasizes spiritual, aesthetic, and nonconsumptive values in nature

Hydric soil - a soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation; field indicators of hydric soils can include: a thick layer of decomposing plant material on the surface; the odor of rotten eggs; and colors of bluish–gray, gray, black, or sometimes gray with contrasting brighter spots of color

Hydrodynamics - the motion of water that generally corresponds to its capacity to do work such as transport sediments, erode soils, flush pore waters in sediments, fluctuate vertically, etc. Velocities can vary within each of three flow types: primarily vertical, primarily bidirectional and horizontal, and primarily unidirectional and horizontal. Vertical fluxes are driven by evapotranspiration and precipitation. Bidirectional flows are driven by astronomic tides and wind-driven seiches. Unidirectional flows are downslope movement that occurs from seepage slopes and floodplains.

Hydrogeomorphology - a branch of science (geology) that studies the movement of subsurface water through rocks, either as underground streams or percolating through porous rocks.

Hydrology - the study of the cycle of water movement on, over and through the earth's surface; the science dealing with the properties, distribution, and circulation of water

Hydroperiod - depth, duration, seasonality, and frequency of flooding

Hydrostatic pressure - the pressure water exerts at any given point when a body of water is in a still motion

Hypersaline - extremely saline, generally over 30 ppt salinity (average ocean water salinity)

Hypoxic - waters with dissolved oxygen less than 2 mg/L

IMPLAN - a micro-computer-based input-output (IO) modeling system (see Input-output model below). With IMPLAN, one can estimate 528 sector I-O models for any region consisting of one or more counties. IMPLAN includes procedures for generating multipliers and estimating impacts by applying final demand changes to the model.

Indirect impacts - the changes in sales, income or employment within the region in backward-linked industries supplying goods and services to tourism businesses. The increase in sales of linen supply firms that result from more motel sales is an indirect effect of visitor spending.

Induced impacts - the increased sales within the region from household spending of the income earned in tourism and supporting industries. Employees in tourism and supporting industries spend the income they earn from tourism on housing, utilities, groceries, and other consumer goods and services. This generates sales, income and employment throughout the region's economy.

Infauna - plants that live in the sediment

Informed consent - an ethical guideline for conducting social science research. Informed consent emphasizes the importance of both accurately informing research participants as to the nature of the research and obtaining their verbal or written consent to participate. The purpose, procedures, data collection methods and potential risks (both physical and psychological) should be clearly explained to participants without any deception.

Infralittoral - a sub-area of the sublittoral zone where upward-facing rocks are dominated by algae, mainly kelp

Input-output model (I-O) - an input-output model is a representation of the flows of economic activity between sectors within a region. The model captures what each business or sector must purchase from every other sector in order to produce a dollar's worth of goods or services. Using such a model, flows of economic activity associated with any change in spending may be traced either forwards (spending generating income which induces further spending) or backwards (visitor purchases of meals leads restaurants to purchase additional inputs -- groceries, utilities, etc.). Multipliers may be derived from an input-output models (see multipliers).

Instrumental values - the usefulness of something as a means to some desirable human end. Natural resource examples include economic and life support values associated with natural products and ecosystem functions (see non-instrumental values).

Intergenerational equity - the perceived fairness in the distribution of project costs and benefits across different generations, including future generations not born yet

Interstices - a space that intervenes between things; especially one between closely spaced things

Intertidal - alternately flooded and exposed by tides

Intrinsic values - values not assigned by humans but are inherent in the object or its relationship to other objects

Invasive species - a species that does not naturally occur in a specific area and whose introduction is likely to cause economic or environmental harm

Invertebrate - an animal with no backbone or spinal column; invertebrates include 95% of the animal kingdom

Irregularly exposed - refers to coastal wetlands with surface exposed by tides less often than daily

Lacunar - a small cavity, pit, or discontinuity

Lacustrine - pertaining to, produced by, or formed in a lake

Lagoons - a shallow stretch of seawater (or lake water) near or communicating with the sea (or lake) and partly or completely separated from it by a low, narrow, elongate strip of land

Large macroalgae - relatively shallow (less then 50 m deep) subtidal algal communities dominated by very large brown algae. Kelp and other large macroalgae grow on hard or consolidated substrates forming extensive three-dimensional structures that support numerous flora and fauna assemblages.

Large-scale commercial fishing - fishing fleets that are owned by corporations with large capital investments, and are highly mobile in their global pursuit of fish populations

Littoral - refers to the shallow water zone (less than 2 m deep) at the end of a marine water body, commonly seen in lakes or ponds

Longitudinal studies - social science research designed to permit observations over an extended period of time (see trend studies, cohort studies, and panel studies)

Macrofauna - animals that grow larger than 1 centimeter (e.g., animals exceeding 1 mm in length or sustained on a 1 mm or 0.5 mm sieve)

Macroinvertebrate - animals without backbones that can be seen with the naked eye (caught with a 1 mm^2 mesh net); includes insects, crayfish, snails, mussels, clams, fairy shrimp, etc

Macrophytes - plant species that are observed without the aid of an optical magnification e.g., vascular plants and algae

Mangroves - swamps dominated by shrubs that live between the sea and the land in areas that are inundated by tides. Mangroves thrive along protected shores with fine-grained sediments where the mean temperature during the coldest month is greater than 20º C, which limits their northern distribution.

Marine polyps - refer to the small living units of the coral that are responsible for secreting calcium carbonate maintaining coral reef shape

Market price method - estimates economic values for ecosystem products or services that are bought and sold in commercial markets

Marshes (marine and freshwater) - coastal marshes are transitional habitats between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water tidally or seasonally. Freshwater species are adapted to the short- and long-term water level fluctuations typical of freshwater ecosystems.

Mast - the nuts of forest trees accumulated on the ground

Measurement error - a type of survey error that occurs when a respondent's answer to a given question is inaccurate, imprecise, or cannot be compared to other respondent's answers

Meiofauna - diverse microorganisms that are approximately between .042 mm and 1 mm in size

Meristematic - the ability to form new cells that separate to form new tissues

Mesocosm - experimental tanks allowing studies to be performed on a smaller scale

Metadata - data that describes or provides background information on other data

Microfauna - animals that are very small and best identified with the use of a microscope, such organisms include protozoans and nematodes

Microinvertebrates - invertebrate animals that are so small they can only be observed with a microscope

Micro-topography - very slight changes in the configuration of a surface including its relief and the position of its natural and man-made features

Migratory - a creature that moves from one region to another when the seasons change

Morphology - the study of structure and form, either of biological organisms or features of the earth surface

Mottling - contrasting spots of bright colors in a soil; an indication of some oxidation or ground water level fluctuation

Mudflat - bare, flat bottoms of lakes, rivers and ponds, or coastal waters, largely filled with organic deposits, freshly exposed by a lowering of the water level; a broad expanse of muddy substrate commonly occurring in estuaries and bays

Multipliers - capture the size of the secondary effects in a given region, generally as a ratio of the total change in economic activity in the region relative to the direct change. Multipliers may be expressed as ratios of sales, income or employment, or as ratios of total income or employment changes relative to direct sales. Multipliers express the degree of interdependency between sectors in a region's economy and therefore vary considerably across regions and sectors

Nanoplankton - plankton of minute size, generally size range is from 2 to 20 micrometers

Native - an animal or plant that lives or grows naturally in a certain region

Nearshore - nearshore waters begin at the shoreline or the lakeward edge of the coastal wetlands and extend offshore to the deepest lakebed depth contour, where the thermocline typically intersects with the lake bed in late summer or early fall

Nekton - free-swimming aquatic animals (such as fish) essentially independent of wave and current action

Non-instrumental values - something that is valued for what it is; a good of its own; an end in itself. Natural resource examples include aesthetic and spiritual values found in nature (see instrumental values)

Non-market goods and services - goods and services for which no traditional market exists whereby suppliers and consumers come together and agree on a price. Many ecosystem services and environmental values fall under this category

Non-point source - a source (of any water–carried material) from a broad area, rather than from discrete points

Nonresponse error - a type of survey error that occurs when a significant proportion of the survey sample do not respond to the questionnaire and are different from those who do in a way that is important to the study

Non-use values - also called "passive use" values, or values that are not associated with actual use, or even the option to use a good or service

Norms - perceived standards of acceptable attitudes and behaviors held by a society (social norms) or by an individual (personal norms). Serve as guideposts for what is appropriate behavior in a specific situation.

Nuisance species - undesirable plants and animals, commonly exotic species

Null hypothesis - a statement about the values of one or more parameters usually describing a condition of no change or difference

Nutria - a large South American semiaquatic rodent (*Myocastor coypus*) with webbed hind feet that has been introduced into parts of Europe, Asia, and North America

Nutrient - any inorganic or organic compound that provides the nourishment needed for the survival of an organism

Nutrient cycling - the transformation of nutrients from one chemical form to another by physical, chemical, and biological processes as they are transferred from one trophic level to another and returned to the abiotic environment

Octocorals - corals with eight tentacles on each polyp. There are many different forms that may be soft, leathery, or even those producing hard skeletons.

Oligohaline - an area of an estuary with salinities between 0.5 and 5.0 ppt

Oligotrophic - a water body that is poor in nutrients. This refers mainly to lakes and ponds

One-hundred year flood - refers to the floodwater levels that would occur once in 100 years, or as a 1.0 percent probability per year

Opportunity cost - the cost incurred when an economic decision is made. This cost is equal to the benefit of the most highly valued alternative that would have been gained if a different decision had been made. For example, if a consumer has $2.00 and decides to purchase a sandwich, the economic cost may be that consumer can no longer use that money to buy fruit.

Option value - the value associated with having the option or opportunity to benefit from some resource in the future

Organic - containing carbon, but possibly also containing hydrogen, oxygen, chlorine, nitrogen, and other elements

Organic material - anything that is living or was living; in soil it is usually made up of nuts, leaves, twigs, bark, etc.

Osmotic stress - water stresses due to differences in salinity between an organism and its aquatic environment

Outdoor recreation conflict - defined as behavior of an individual or group that is incompatible with the social, psychological or physical goals of another person or group

Oyster beds - dense, highly structured communities of individual oysters growing on the shells of dead oysters

Panel studies - longitudinal research that studies the same set of people through time in order to investigate changes in individuals over time (see longitudinal studies)

Pelagic - pertaining to, or living in open water column

Personal area network (PAN) - a computer network used for communicating between computer devices (including telephones and personal digital assistants) and a person

Petiole - the stalk of a leaf, attaching it to the stem

pH - a measure of the acidity (less than 7) or alkalinity (greater than 7) of a solution; a pH of 7 is considered neutral

Phenology - refers to the life stages a plant/algae experiences (e.g., shoot development in kelp)

Physiographic setting - the location in a landscape, such as stream headwater locations, valley bottom depression, and coastal position. Similar to geomorphic setting.

Physiography - a description of the surface features of the Earth, with an emphasis on the mode or origin

Phytoplanktivores - animals that eat planktonic small algae that flow in the water column

Phytoplankton - microscopic floating plants, mainly algae that are suspended in water bodies and are transported by wave currents because they cannot move by themselves swim effectively against a current.

Piscivorous - feeding on fish

Planktivorous - eating primarily plankton

Plankton - plant and animal organisms, generally microscopic, that float or drift in water

Pneumatocysts - known as gas bladders or floaters that help the plant stay afloat such as the bladders seen in the brown alga *Macrocystis*

Pneumatophores - specialized roots formed on several species of plants occurring frequently in inundated habitats; root is erect and protrudes above the soil surface

Polychaete - a group of chiefly marine annelid worms armed with setae, or bristles, extending from most body segments

Population - a collection of individuals of one species or mixed species making up the residents of a prescribed area

Population list - in social science survey research, this is the list from which the sample is drawn. This list should be as complete and accurate as possible and should closely reflect the target population.

ppt - parts per thousand. The salinity of ocean water is approximately 35 ppt

Precision - a statistical term that refers to the reproducibility of the result or measurement. Precision is measured by uncertainty and is usually expressed as the standard error or some confidence interval around the estimated mean.

Prop roots - long root structures that extend midway from the trunk and arch downward creating tangled branching roots above and below the water's surface, such as the mangrove *Rhizophora*

Propagules - a structure (cutting, seed, spore, rhizome, etc.) that causes the continuation or increase of a plant, by sexual or asexual reproduction

Protodeltaic - similar in form to the early stages of delta formation

Pseudofeces - material expelled by the oyster without having gone through the animal's digestive system

Quadrats - are rectangular, or square shaped instruments used to estimate density, cover and biomass of both plants and animals

Quality assurance/quality control plan - a detailed plan that describes the means of data collection, handling, formatting, storage, and public accessibility for a project

Random utility models - a non-market valuation technique that focuses on the choices or preferences of recreationists among alternative recreational sites. Particularly appropriate when substitutes are available to the individual so that the economist is measuring the value of the quality characteristics of one or more site alternatives (e.g., a fully restored coastal wetland and a degraded coastal wetland).

Receiving water bodies - lakes, estuaries, or other surface waters that have flowing water delivered to them

Recruitment - the process of adding new individuals to a population or subpopulation (as of breeding individuals) by growth, reproduction, immigration, and stocking; also a measure (as in numbers or biomass) of recruitment

Redox potential - oxidation-reduction potential; often used to quantify the degree of electrochemical reduction of wetland soils under anoxic conditions

Reference condition - set of selected measurements or conditions of minimally impaired waterbodies characteristic of a waterbody type in a region

Reference site - a minimally impaired site that is representative of the expected ecological conditions and integrity of other sites of the same type and region

Reflectance - The ratio of the light that radiates onto a surface to the amount that is reflected back

Regime - a regular pattern of occurrence or action

Reliability - the likelihood that a given measurement procedure or technique will yield the same result each time that measure is repeated (i.e., reproducibility of the result) (see Precision)

Remote sensing - the process of detecting and monitoring physical characteristics of an area by measuring its reflected and emitted radiation and without physically contacting the object

Restoration - the process of reestablishing a self-sustaining habitat that in time can come to closely resemble a natural condition in terms of structure and function

Restoration monitoring - the systematic collection and analysis of data that provides information useful for measuring restoration project performance at a variety of scales (locally, regionally, and nationally)

Rhizome - somewhat elongate usually horizontal subterranean plant stem that is often thickened by deposits of reserve food material, produces shoots above and roots below, and is distinguished from a true root in possessing buds, nodes, and usually scale-like leaves

Riparian - a form of wetland transition between permanently saturated wetlands and upland areas. These areas exhibit vegetation or physical characteristics reflective of permanent surface of subsurface water influence. Lands along, adjacent to, or contiguous with perennially and intermittently flowing rivers and streams, glacial potholes, and the shores of lakes and reservoirs with stable water levels are typically riparian areas. Excluded are such sites as ephemeral streams or washes that do not exhibit the presence of vegetation dependent upon free water in the soil.

Riverine - of, or associated with rivers

Riverine forests - forests found along sluggish streams, drainage depressions, and in large alluvial floodplains. Although associated with deepwater swamps in the SE United States, riverine forests are found throughout the US and do not exhibit prolonged flooding.

Rocky shoreline - extensive hard bottom littoral habitats on wave-exposed coasts

RVD (recreational visitor day) - one RVD is defined as 12 hours of use in some recreational activity. This could be one person using an area for 12 hours, or 2 people using an area for 6 hours each, or any combination of people and time adding to 12 hours of use.

Salinity - the concentration of dissolved salts in a body of water; commonly expressed as parts per thousand

Salt pans - an undrained natural depression in which water gathers and leaves a deposit of salt on evaporation

Sample - in social science survey research, this is a set of respondents selected from a larger population for the purpose of a survey

Sampling designs - the procedure for selecting samples from a population and the subsequent statistical analysis

Sampling error - a potential source of survey error that can occur when researchers survey only a subset or sample of all people in the population instead of conducting a census. To minimize this error the sample should be as representative of the population as possible.

Satisfaction - in outdoor recreation, satisfaction is defined as the difference between desired and achieved goals. Can be measured through surveys of recreation participants.

SAV (submerged aquatic vegetation) - marine, brackish, and freshwater submerged aquatic vegetation that grows on soft sediments in sheltered shallow waters of estuaries, bays, lagoons, and lakes

Seasonality - the change in naturally cycles, such as lunar cycles and flooding cycles, from one season to the next

Secondary data - information that has already been assembled, having been collected for some other purpose. Sources include census reports, state and federal agency data, and university research.

Secondary effects - the changes in economic activity from subsequent rounds of re-spending of tourism dollars. There are two types of secondary effects: indirect effects and induced effects.

Sector - a grouping of industries that produce similar products or services. Most economic reporting and models in the U.S. are based on the Standard Industrial Classification system (SIC code). Tourism is more an activity or type of customer than an industrial sector. While hotels (SIC 70) are a relatively pure tourism sector, restaurants, retail establishments and amusements sell to both tourists and local customers. There is therefore no simple way to identify tourism sales in the existing economic reporting systems, which is why visitor surveys are required to estimate tourist spending.

Sediment porewater - water in the spaces between individual grains of sediment

Seiches - a sudden oscillation of the water in a moderate-size body of water, caused by wind

Seine - a net weighted at the bottom with floats at the top so it remains vertical in the water. A seine can be towed behind a boat or smaller versions, attached to poles, may be operated by hand.

Senescence - the growth phase in a plant or plant part (as a leaf) from full maturity to death, also applies to winter dormancy

Sessile - plants that are permanently attached or established; animals that do not freely move about

Simple random sampling (SRS) - in survey research, when each member of the target population has an equal change of being selected. If a population list exists, SRS can be achieved using a computer-generated random numbers.

Small-scale commercial fishing - fishing operations that have relatively small capital investment and levels of production, and are more limited in terms of mobility and resource options (compared to large-scale operations). Terms that are commonly used to describe small-scale fishermen include native, coastal, inshore, tribal, peasant, artisanal, and traditional.

Social capital - describes the internal social and cultural coherence of society, the norms and values that govern interactions among people and the institutions in which they are embedded

Social impact assessment (SIA) - analysis conducted to assess, in advance, the social consequences that are likely to follow from specific policy actions and alternatives. Social impacts in this context refers to the consequences to human populations that alter the ways in which people live, work, play, relate to one another, organize and generally cope as members of society.

Social network mapping - community assessment research method used to collect, analyze, and graphically represent data that describe patterns of communication and relationships within a community

Socioeconomic monitoring - tracking of key indicators that characterize the economic and social state of a community

Soft bottom - loose, unconsolidated substrate characterized by fine to coarse-grained sediment

Soft shoreline - sand beaches, dunes, and muddy shores. Sandy beaches are stretches of land covered by loose material (sand), exposed to and shaped by waves and wind.

Stakeholders - individuals, groups, or sectors that have a direct interest in and/or are impacted by the use and management of natural resources in a particular area, or that have responsibility for management of those resources

Statistical protocol - a method of a analyzing a collection of observed values to make an inference about one or more characteristic of a population or unit

Strands - a diffuse freshwater stream flowing through a shallow vegetated depression on a gentle slope

Structural habitat characteristics - characteristics that define the physical composition of a habitat

Subsistence - describes the customary and traditional uses of renewable resources (i.e., food, shelter, clothing, fuel) for direct personal/family consumption, sharing with other community members, or for barter. Subsistence communities are often held together by patterns of natural resource production, distribution, exchange, and consumption that helps maintain a complex web of social relations involving authority, respect, wealth, obligation, status, power and security.

Subtidal - continuously submerged; an area affected by ocean tides

Supralittoral region - is that area which is above the high tide mark receiving splashing from waves

Target population - the subset of people who are the focus of a survey research project

Taxa - a grouping of organisms given a formal taxonomic name such as species, genus, family, etc. (singular form is taxon)

Temporal - over time

Thermocline - the region in a thermally stratified body of water which separates warmer oxygen-rich surface water from cold oxygen-poor deep water and in which temperature decreases rapidly with depth

Tide - the rhythmic, alternate rise and fall of the surface (or water level) of the ocean, and connected bodies of water, occurring twice a day over most of the Earth, resulting from the gravitational attraction of the Moon, and to a lesser degree, the Sun

Topography - the general configuration of a land surface or any part of the Earth's surface, including its relief and the position of its natural and man–made features

Transect - two types of transects, point and line. Point intercept transect methods is performed by placing a point frame along a set of transect lines. Line transects are when a line is extended from one point to the next within the designated sample area

Transient - passing through or by a place with only a brief stay or sojourn

Transit - a surveying instrument for measuring horizontal and vertical angles; appropriate to help determine actual location of whale surfacing. It contains a small telescope that is placed on top of a tripod.

Travel cost method (TCM) - TCM is used to estimate monetary value of a geographical site in its current condition (i.e., environmental health, recreational use capacity, etc.) by site-users. Individuals or groups report travel-related expenditures made while on trips to single and multiple recreational sites. Market values are used.

Trend studies - longitudinal research that studies changes within some general population over time (see longitudinal studies)

Trophic - refers to food, nutrition, or growth state

Trophic level - a group of organisms united by obtaining their energy from the same part of the food web of a biological community

Turf - cover (the ground) with a surface layer of grass or grass roots

Unconsolidated - loosely arranged

Utilitarian value - valuing some object for its usefulness in meeting certain basic human needs (e.g., food, shelter, clothing). Also see human-dominant values

Validity - refers to how close to a true or accepted value a measurement lies

Vibracore - refers to a high frequency, low amplitude vibration, coring technique used for collecting sediment samples without disrobing the sample

Viviparous - producing living young instead of eggs from within the body in the manner of nearly all mammals, many reptiles, and a few fishes; germinating while still attached to the parent plant

Water column - a conceptual volume of water extending from the water surface down to, but not including the substrate. It is found in marine, estuarine, river, and lacustrine systems.

Watershed - surface drainage area that contributes water to a lake, river, or other body of water; the land area drained by a river or stream

Willingness-to-pay - the amount in goods, services, or dollars that a person is willing to give up to get a particular good or service

Zonation - a state or condition that is marked with bands of color, texture, or plant species

Zooplanktivorus - animals that feed upon zooplankton

Zooplankton - free-floating animals that drift in the water, range from microscopic organisms to larger animals such as jellyfish

References

http://www.aswm.org/lwp/nys/glossary.htm

http://water.usgs.gov/nwsum/WSP2425/glossary.html

http://water.usgs.gov/wicp/acwi/monitoring/glossary.html

http://www.webster.com